SOIL, WATER, AND CROP MANAGEMENT

ON NEWLY IRRIGATED LANDS

in the Dakotas

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Growth Through Agricultural Progress

SOIL, WATER, AND CROP MANAGEMENT ON NEWLY IRRIGATED LANDS IN THE DAKOTAS

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In the Dakotas, estimates indicate that there are a potential 1½ million acres of land that can be irrigated from the Missouri River. Successful conversion from dryland to irrigation agriculture over such a vast area presents many soil, water, and crop-management problems. Agriculturists have the answers for only a few of them in an area where irrigation has been of minor importance. It is the purpose of this report to summarize the principal findings from a research program of soil, water, and crop management conducted from 1950 through 1958, by the Soil and Water Conservation Research Division of the Agricultural Research Service in cooperation with the North and South Dakota Agricultural Experiment Stations and the U.S. Bureau of Reclamation on development farms provided by the latter agency.

The Garrison Diversion Unit in central and eastern North Dakota, and the Oahe Unit in north-central South Dakota are parts of the proposed water development plan of the Missouri River basin project. Both units are being investigated by the Bureau of Reclamation and initial construction is planned for about 1963. The Oahe Unit is estimated to include more than 500,000 irrigable acres and the Garrison Diversion Unit, about 1 million acres. Water for the Garrison Diversion Unit will come from the Garrison Reservoir, and that for the Oahe Unit will come from the Oahe Reservoir. Both reservoirs are located on the Missouri River.

THE PROGRAM OF AGRICULTURAL RESEARCH

The development farm system used in the irrigated west has played a key role in the irrigation research activities in the Dakotas. These farms are established and developed as pilot units in advance of irrigation development. The U.S. Bureau of Reclamation provides the land, develops the farm unit with the necessary buildings and fences, installs the irrigation system, and supervises the operation of the farm. However, the farms are leased to private operators under terms somewhat similar to the usual landlord-tenant agreement. A maximum of 25 percent of the area can be used by research agencies.

Each farm is located on a soil that is representative of a considerable area in the project. The climate is also taken into consideration when choosing a farm. Water is pumped to the farms from nearby rivers.

This arrangement permits the research agencies to conduct soil, water, and crop-production research in the particular area for 5 years or more. Research results and plans for subsequent years are reviewed annually with State and Federal agencies.

RESEARCH LOCATIONS

The Northern Great Plains Field Station (fig. 1) at Mandan has served as headquarters for most of the research conducted at the Mandan, Bowbells, and Deep River Development Farms. South Dakota State College at Brookings has been the headquarters for the work at the Huron, Redfield, and Shadehill Development Farms.

The Huron Development Farm, the first farm to be established in the Missouri River basin project, was located 4 miles southwest of Huron,

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TABLE 1.—*Chemical properties of profiles from soils on which experimental work has been conducted*

Soil series	Horizon	Depth	Textural class [1]	pH (paste)	Total nitrogen	Cation exchange capacity
		Inches			*Percent*	*meq./100g*
Houdek loam	A_1	0–5	l	6. 1	0. 279	23. 3
	B_2	5–14	cl	7. 1	. 143	21. 3
	B_3	14–18	cl	8. 2	. 053	13. 9
	C_{ca}	18–42	cl	8. 3	. 026	15. 7
	C_1	42–60	l	8. 4	. 018	12. 1
Huff loam [2]	----------	0–7	Loam underlain by sand.	7. 6	. 185	25. 8
		7–21		7. 7	. 157	24. 2
Williams loam	A_p	0–5	l	6. 2	. 252	23. 6
	B_{21}	5–9	cl	6. 0	. 125	22. 7
	B_{22}	9–13	cl	6. 6	. 110	21. 6
	C_{ca}	13–25	cl	7. 9	----------	15. 9
	C_1	25–40	l	8. 4	----------	15. 8
	C_2	40–60	l	8. 2	----------	15. 8
Harmony silty clay loam	A_1	0–7	si cl l	6. 6	. 294	30. 7
	A_2	7–11	si cl l	6. 9	. 190	29. 1
	B_2	11–18	si cl l	7. 0	. 113	28. 7
	B_3	18–22	si cl l	7. 9	. 087	24. 2
	C_{1ca}	22–40	si cl l	7. 9	. 041	19. 4
	C_2	40–60	si cl l	7. 8	. 036	23. 1
	C_3	60–80	si cl l	7. 8	. 038	24. 9
Beotia silt loam	A_1	0–10	si l	7. 0	. 170	24. 3
	A_3	10–16	si l	7. 0	. 110	22. 3
	B_1	16–23	si l	7. 3	. 090	21. 8
	C_{1ca}	23–56	si l	8. 2	. 040	----------
	C_{2ca}	56–66	si l	8. 2	. 030	----------
Cheyenne loam [2]	----------	0–6	Loam grading into sandy or gravelly loam.	6. 6	----------	21. 0
		6–12		6. 7	----------	23. 0
		12–18		7. 3	----------	22. 0
		18–24		7. 8	----------	19. 0
		24–30		7. 8	----------	15. 0

[1] l=loam; cl=clay; si cl=silty clay; si=silt.
[2] Samples collected at arbitrary depths; no attempt made to separate horizons.

S. Dak., on glacial till soils. Water from the James River was made available in the summer of 1946. The main soil series, Houdek stony loam, occurs on undulating topography, is fertile, has good tilth, and is moderately permeable at the surface with the glacial till substrata being slowly permeable. The soil profile has about 5 inches of loam, with a calcareous glacial till subsoil starting at about 14 inches (table 1). Only small amounts of fertilizer were used in the dryland grain operation carried on at this farm before 1946. An active research program, which included fertility studies with corn, wheat, and alfalfa, as well as grazing studies with various grasses, was conducted at this location until 1952 when the farm was discontinued.

The Mandan Development Farm, located just west of the city of Mandan, N. Dak., was first irrigated with water pumped from the Heart River in the summer of 1948. Soil and water research was conducted on this farm in 1948 and 1949. In 1950 the program was enlarged to include soil management and forage crop work.

The experimental site was on Huff loam, a dark grayish-brown soil underlain by sandy alluvium, with calcareous material occurring at about 12 inches. The surface was nearly level with good drainage, but the farm was underlain with a shallow water table. Portions of this area, used before 1948 as a dryland farm by the State Training School, received large amounts of manure. This treatment caused the farm to vary in soil fertility. Fertilizer and water-use studies with corn, alfalfa, potatoes, small grains, sugar beets, and grasses

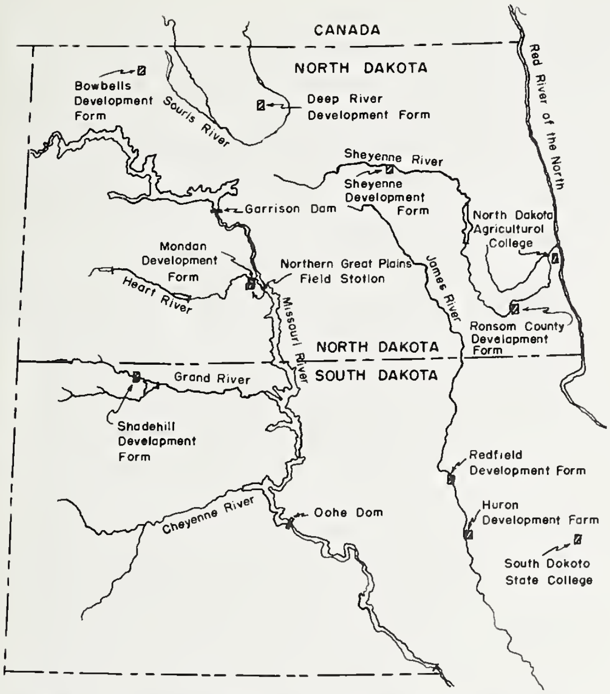

FIGURE 1.—Locations of the experiment stations and development farms.

were conducted at this location. Corn, small grain, grass, and legume variety trials were carried out and seed-production studies were made with various species of grass. The soil-management work at this location was discontinued in 1953 and the forage crop work in 1957. The farm is presently being operated by the State Training School.

Operations were started in 1948 at the Bowbells Development Farm located 4½ miles east of Bowbells, N. Dak. Water was pumped to the farm from the Des Lacs River. The soil series on this farm was Williams loam, which occurred on an undulating and generally rolling topography. The surface horizons, made up of about 10 inches of friable loam with good tilth, were underlain by a calcareous, poorly drained till material. Before 1948 this farm had been under dryland and no commercial fertilizer had been used. Before irrigation, the water table was about 20 feet below the soil surface.

Research was conducted on the Bowbells farm in 1948 and 1949. In 1950 the work was expanded, but all research was discontinued in 1952 because results indicated that drainage would become a serious problem if the area was extensively irrigated. Farming operations were discontinued the same year. Research conducted at this location dealt with fertilizer and water-use investigations with small grains, corn, potatoes, sugar beets, alfalfa, and grasses. A small area of the farm also was devoted to small grains, grass, and legume variety studies.

Work on the Redfield Development Farm, located 6 miles east and 1 mile north of Redfield, S. Dak., was started in 1948, using water from the James River. Beotia silt loam and Harmony silty clay loam were the soil series on which the work was conducted. These soils occur on the level portions of the glacial lake Dakota plains and both have lake deposited silts and clays as parent material (*37*).[2] The Beotia soils are well drained, whereas the subsoils of the Harmony silty clay loam are only moderately permeable. Both soils are fertile and have good tilth. Before irrigation, the farm unit was used principally for dryland corn and small-grain production.

Research investigations at Redfield included variety trials with corn, potatoes, soybeans, grasses, and legumes. To determine the crop rotation best suited to irrigated farming in the James River basin and to compare crop performance on irrigated and nonirrigated land under similar conditions, four rotation experiments were begun in 1949. Rotations studied were a wheat-corn and a wheat-alfalfa-alfalfa-corn sequence on irrigated and nonirrigated land. In 1954 another irrigated rotation study was initiated to compare a barley-corn-corn rotation with a barley-alfalfa-alfalfa-corn-corn rotation. These experiments were designed to determine how alfalfa affected the fertilizer requirements of crops in the rotation and the best way to fertilize crops in a rotation with and without a legume.

Studies involving grass seed and hay production, water use by several crops, and methods of corn planting were undertaken at this location. An active research program is still in progress.

The Shadehill Development Farm, located 13 miles south of Lemmon, S. Dak., was established on a Cheyenne loam in 1952. This fertile, well-drained soil developed from alluvium over gravel beds on broad, flat terraces. The soil, which has no appreciable amounts of salt, has a shallow A

[2] Italic numbers in parentheses refer to Literature Cited, pp. 33–34.

horizon with a lime accumulation at the 18- to 24-inch depth.

The purpose of the Shadehill farm, which had been a dryland native range before 1952, was to determine the effects of applying water high in sodium, moderately high in total salts, and having high bicarbonate-calcium ratios on crop production and on the accumulation of salts and exchangeable sodium in the soil. Research at this location has been discontinued.

The Deep River supplies irrigation water for the Deep River Development Farm, located 3½ miles northwest of Upham, N. Dak. Gardena loam, the major soil series on which the research work was conducted, occurs on a nearly level upland delta and has coarse-textured glacial lacustrine sediments as parent material. The A horizon in this fertile soil is shallow with no B, and the entire profile is low in total salts and exchangeable sodium (table 2). This location, which had been a dryland grain farm for 40 years before irrigation was developed, had received no fertilizer up to 1953. The water table was about 12 feet under the experimental area before the first irrigation.

Research conducted at this location included a comparison of a barley-corn-potato rotation with a barley-alfalfa-alfalfa-alfalfa-corn-potato rotation to evaluate the need for and crop response to nitrogen and phosphorus in a rotation with and without alfalfa. Water-use and fertilizer studies with corn, potatoes, sugar beets, alfalfa, and grasses were carried out. Experiments were conducted to evaluate the use of fertilizers to correct the mineral deficiencies found in subsoils exposed during land-leveling operations. Forage production of various grass and legume mixtures was studied, as well as grass, legume, and small-grain variety trials. Farming operations are still continuing at this farm, but the research program was discontinued in 1957.

The Sheyenne Development Farm, located just west of Sheyenne, N. Dak., has Oakes and Wells loam as the major soil series. These soils, which developed on a nearly level glacial outwashed plain from glacial alluvium, are sandy and have moderately high permeability. Tilth in these soils is good, but the fertility level is low. Before 1957 this area was used for small-grain production under dryland conditions. The biggest problem on these sandy soils has been drought damage to crops in most years. No research has been carried on at this location.

The last to be developed was the Ransom County Development Farm, located 6 miles northeast of Lisbon, N. Dak. Irrigation was begun in the summer of 1958 with water from the Sheyenne River. The main soil series, Sheldon loam, was developed on a nearly level delta area. It has deep A and B horizons with lime at a depth of 4 to 5 feet, good internal drainage, and high fertility. Dryland-corn and small-grain farming was practical on this farm before the irrigation system was installed in 1958. Research was started in 1958 by the North Dakota Agricultural College and is continuing.

TABLE 2.—*Some chemical properties of Garden loam at Upham, N. Dak.*

Soil horizon	Depth	Total nitrogen	$NaHCO_3$ soluble P [1]	Paste pH	Exchangeable K	Cation exchange capacity	$CaCO_3$	Hydrochloric acid extractable zinc
	Inches	*Percent*	*P.p.m.*		*Meq./100g.*	*Meq./100g.*	*Percent*	*P.p.m.*
A_{1p}	0–8	0.18	8.2	7.3	0.79	19.0	0	3.6
AC	8–11	.10	2.4	7.4	.30	15.0	.1	2.0
C_1	11–23	.06	3.0	8.0	.18	10.0	7.6	.9
D_1	23–28	.03	2.9	8.1	.17	6.8	7.0	1.1
D_2	28–43	.06	1.8	8.2	.39	12.6	6.5	.7
D_3	43–52	.02	3.8	8.5	.21	6.2	7.3	.8

[1] Multiply by 4.58 to obtain pounds of P_2O_5 per acre 6 inches.

WATER TABLE LEVELS AT RESEARCH LOCATIONS

In many areas excess water from irrigation and seepage from reservoirs, canals, and ditches has greatly reduced plant growth and yield. In order to determine the drainage facilities needed, the Bureau of Reclamation has made water table measurements at all experimental locations.

At the Huron Development Farm, there was no instance of less than 4 feet to the ground water surface. The water table, generally about 8 feet below the soil surface, rose about 2 feet during the irrigating season but dropped to the original level each winter. There was no indication of a permanent change in water table depth during the time the farm was operated.

The water table readings at the Mandan Development Farm were 7 to 8 feet below the soil surface during the course of the experiments. Water level in the Heart River had an influence on the water table level under the farm. No permanent increase in the water table levels was observed from 1948 to 1957.

At the Bowbells Development Farm there was a rise in the water table from 1948 to 1952. In the summer of 1951 it rose to within 3 feet of the soil surface at some locations. During the following winter it dropped to a 9-foot level. In 1952 a general rise was recorded from the first of May to the first of November.

By 1955 the water table at the Redfield Development Farm (average of 10 observation wells) had risen 10 feet above the May 31, 1951, measurement of 18 feet below the soil surface. The water table did not rise in 1956, but in 1957 it rose to within 3 feet of the surface. No change was observed in 1958. The depth from ground surface to the water table was least in August and greatest in April. This distance ranged from about 3 to 18 feet.

At Shadehill the water table receded sharply after irrigation ceased for the season and reached a low in March. The height depended on the intensity and duration of irrigation operations. In 1957 and 1958 after 5 years of irrigation, water table elevations were from ½ to 2 feet below the January 15, 1953, levels. Thus, there was no long term effect of irrigation on the water table.

When the experiments were initiated at the Deep River Development Farm, the water table depth ranged from 12 to 14 feet below the surface. After 5 years of irrigation there was no permanent change in water table levels. Rainfall had a temporary influence on ground water elevations over the entire farm.

These data were collected on irrigated farms surrounded by lands that were not irrigated. If an entire area were irrigated, the water table would be expected to rise more than occurred in the studies reported here.

CLIMATE

Climate in the Dakotas is the continental type with cold winters and warm summers. A summer temperature of 121° F. and a winter temperature of 50° below zero have been recorded at Steele, N. Dak., which is in about the center of the area with which this publication is concerned. A range of more than 140° often occurs between maximum summer and minimum winter temperatures. Temperatures reach 90° or higher on a yearly average, ranging from 14 days in the north to 22 days in the south. Days per year with temperatures of zero or below range from 53 in the north to 33 in the south. The frost-free season ranges from 121 days at Granville, N. Dak., in the northern part to 151 days at Huron, S. Dak., in the southern part.

The Dakotas are in a subhumid region. Average annual precipitation ranges from 14.1 inches at Westhope, N. Dak., in the northern part of the area, to 18.7 inches at Huron. Over 75 percent of the precipitation occurs between April 1 and September 1, of which about 50 percent falls during May and June. Mean annual precipitation in North Dakota from 1886 through 1938 ranged from 8.83 inches in 1936 to 22.60 inches in 1896. During this period, annual precipitation was below 10 inches in 2 years and above 20 inches in 4 years.

Wind velocities are highest in the spring and lowest in the late summer. The relative humidity is higher in the north than in the south, with a seasonal average of about 68 percent for the entire area.

The area has an average of 167 clear days during the year. The sun shines more than 15 hours a day from the middle of May until the end of July. These days make it possible to grow many crops in a comparatively short growing season. Damage to crops from hail is common in the Dakotas. Hail losses are heavy in both North and South Dakota as judged by the amount of hail insurance sold. Generally, only small areas receive damage in any one storm. In local areas, however, loss is oc-

casionally complete. At Mandan, during a 15-year period (1945–59) there have been 5 years in which there has been serious damage to experimental plots.

QUALITY OF RIVER WATER

The quality of water available for irrigation determines the extent to which it can be used. Water quality also determines the kind of soil-management practices necessary to avoid reduction in crop yields by the effects of saline water on plant growth, or by water high in sodium on the soil.

Where water quality is satisfactory, irrigation on a limited scale could be, or is being practiced along almost every stream in the area covered by this publication. In this discussion, only the waters that could be used to irrigate large areas are evaluated. The streams flowing through these areas are shown in figure 1. Two major aspects of water quality will be discussed here; namely, salinity and nutrient content.

Salinity Content

In table 3 are shown summary values for the basic analytical data collected from several sites and on several dates along the rivers mentioned above (*26*, *27*, *38*). Data were selected to represent the quality of water during the irrigating season, from samples that were collected between May 1948 and June 1957. No data on well or subsurface water are included.

All of these waters are somewhat saline (table 3), as indicated by their electrical conductivity. However, they can be used safely for irrigation when certain precautionary measures are practiced. The pH range is desirable, and the sodium content is not excessive.

The U.S. Salinity Laboratory (*35*) classification, on the basis of both conductivity and sodium absorption ratio (SAR) values, divides these rivers into two classes with one borderline case (table 4). The Missouri River has a low salinity hazard and can be used wherever a moderate amount of leaching occurs. Crops with a moderate amount of salt tolerance will be unaffected by the salinity of this water. However, the waters from the other rivers have higher salt concentrations and should be used only on lands with good drainage, under special management to prevent accumulation of salts in the soil. Unless crops with good salt tolerance are grown, yields will probably be reduced by the use of these waters (fig. 2).

FIGURE 2.—Border irrigating alfalfa with siphon tubes at the Mandan Development Farm. (U.S. Bureau of Reclamation photo.)

These rivers do not contain sufficiently large amounts of sodium to cause harm to any but the most sensitive crops. If good management practices were used, these waters would be safe for all soils except those with potential drainage problems.

Also described by the U.S. Salinity Laboratory staff (*35*) is Eaton's concept of "residual sodium carbonate" to classify river waters. This classification (table 4) lists all these rivers as being probably safe for use, as they have low quantities of bicarbonate ion present.

Nutrient Content

The nutrient content of these river waters is shown in table 5. Nitrogen is present in measurable quantities but much below the requirements for normal crop growth. Adequate quantities of sulfur, calcium, magnesium, and potassium would be supplied by the application of a normal supply (1.5–2.0 acre-feet) of irrigation water during the season (*21*). The concentration of boron is adequate for all crop requirements (*3*). No salts were found in toxic concentrations.

TABLE 3.—*Summary of analyses of water from several rivers in North and South Dakota*

River	Location and date [1]	E C	pH	B	Cations					Anions			
					Na	K	Ca	Mg	Total	HCO_3	CO_3	SO_4	Total
		Micro-mhos/cm.		*P.p.m.*	*Meq./l.*	*Meq./l.*	*Meq./l.*	*Meq./l.*	*Meq./l.*	*Meq./l.*	*Meq./l.*	*Meq./l.*	*Meq./l.*
Missouri	N. Dak., S. Dak	568	7. 7	0. 40	2. 30	0. 13	2. 25	1. 32	6. 00	2. 72	0	2. 96	5. 68
Heart	do	925	8. 1	. 68	6. 17	. 21	2. 05	2. 06	10. 49	5. 05	0. 23	5. 04	10. 32
James	do	839	7. 6	. 34	3. 09	. 31	2. 59	2. 71	8. 70	4. 57	. 50	3. 27	8. 34
Sheyenne	N. Dak	1, 050	8. 1	. 38	5. 04	. 31	2. 99	2. 80	11. 14	6. 15	. 40	3. 19	[2] 9. 74
Cheyenne	S. Dak	1, 660	7. 6	. 24	5. 17	. 43	9. 58	4. 85	20. 03	2. 72	. 17	16. 10	18. 99
Souris	N. Dak., S. Dak	759	8. 0	. 10	2. 96	. 74	2. 25	2. 80	8. 75	4. 90	. 27	3. 02	8. 19

[1] Values are means for several locations and dates.
[2] Water contained some chlorides.

TABLE 4.—*Evaluation of several rivers in North and South Dakota used for irrigation purposes* [1]

River	U.S. Salinity Laboratory		Eaton	
	Class	SAR [2]	Residual Na_2CO_3 [3]	Class
Missouri	C2–S1	1.73	None	Safe
Heart	C3–S1	4.31	1.17	Do.
James	C3–S1	1.90	None	Do.
Sheyenne, N. Dak.	C3–S1	2.96	.76	Do.
Cheyenne, S. Dak.	C3–S1	1.92	None	Do.
Souris	C2/C3–S1.	1.86	.12	Do.

[1] Classified according to systems by the U.S. Salinity Laboratory staff. Their classification (*35*, p. 80) involves both conductivity and SAR values.

[2] SAR=Sodium adsorption ratio $\left(SAR=\frac{Na}{\sqrt{\frac{Ca+Mq}{2}}}\right)$

[3] Residual $Na_2CO_3=(CO_3^{--}+HCO_3^{-})-(Ca^{++}+Mg^{++})$.

TABLE 5.—*Nutrients present in water from several rivers in North and South Dakota*

River	Nutrients per acre-foot					
	NO_3–N	S	Ca	Mg	K	B [1]
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Missouri	6.3	129	122	44	14	1.1
Heart	3.8	220	112	68	22	1.8
James	9.0	143	141	70	33	.9
Sheyenne, N. Dak	4.4	139	163	92	33	1.0
Cheyenne, S. Dak	3.8	702	522	160	46	.6
Souris	7.6	132	122	92	79	.3

[1] One pound of B equivalent to 8.81 pounds of borax.

WATER QUALITY STUDIES

Low-quality water (table 6) was used in a study to determine the accumulation of salts and sodium in the soil at the Shadehill Development Farm from 1952 through 1958. A spring flood on the north fork of the Grand River in 1952 filled the Shadehill Reservoir with a water of higher quality than would normally be expected. It was therefore necessary to inject sodium bicarbonate solution into the irrigation water during 1954 and 1955 in order to bring the concentration to the level ultimately expected in the reservoir. However, none was added after 1955. The plots received from four to five irrigations during the growing season, or an average annual application of 25.6 inches of water.

The amount of exchangeable sodium at three soil depths during each year is shown in figure 3. The sodium in the upper 6 inches increased until 1955, and also in the 12- to 18-inch layer until 1956, although not so rapidly. Exchangeable sodium was less in the 30- to 36-inch depth, but

TABLE 6.—*Chemical analyses of water used in water-quality studies at Shadehill, S. Dak.*

Year	Conductivity	pH	Total dissolved solids	Na found [1]	Na possible [2]	Residual Na_2CO_3	Cations				Anions				Total	
							Na	Ca	Na	K	CO_3	HCO_3	SO_4	Cl	Cations	Anions
	$EC \times 10^6$		*P.p.m.*	*Percent*	*Percent*	*Meq./l.*	*Meq./l.*	*Meq./l.*	*Meq./l.*	*Meq./l.*	*Meq./l.*	*Meq./l.*	*Meq./l.*	*Meq./l.*	*Meq./l.*	*Meq./l.*
1953	890	8.0	----------	64.0	94.8	1.22	------	------	------	------	------	------	------	------	------	------
1954 [3]	1,465	8.8	1,000	80.6	100	5.48	11.9	0.7	1.7	0.42	1.67	6.24	6.81	0.29	14.72	15.01
1955 [3]	1,525	8.2	980	80.6	98.5	6.56	13.3	1.7	1.3	.20	1.37	8.14	6.91	.25	16.50	16.67
1956	1,370	8.4	868	76.6	98.1	3.40	10.5	1.4	1.6	.20	1.03	5.37	6.59	.26	13.70	13.25
1958	1,500	8.4	968	80.6	98.0	4.34	12.6	1.4	1.4	.25	1.00	6.10	7.86	.56	15.65	15.52

[1] Soluble-sodium percentage "found" $= (Na^+ \times 100)/(Ca^{++} + Mg^{++} + Na^+)$.

[2] Soluble-sodium percentage "possible" $= (Na^+ \times 100)/[(Ca^{++} + Mg^{++} + Na^+) - (CO_3^{--} + HCO_3^-)]$, where the $CO_3^{--} + HCO_3^-$ deduction does not exceed $Ca^{++} + Mg^{++}$.

[3] Sodium bicarbonate injected into the water from reservoir in order to bring the concentration to the level ultimately expected in the reservoir.

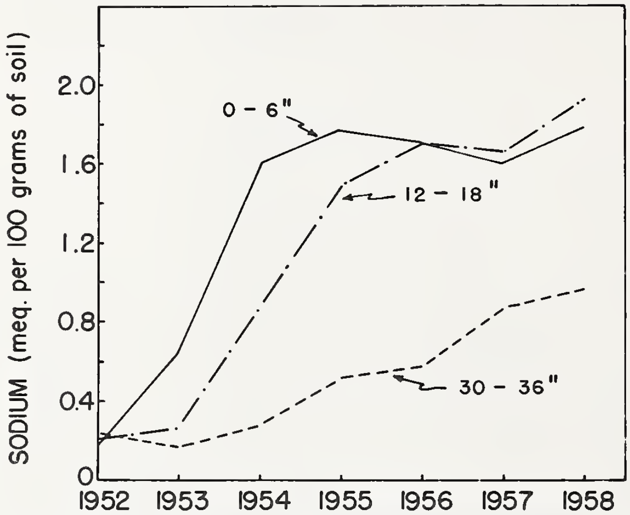

FIGURE 3.—Exchangeable sodium accumulated in a Cheyenne loam profile at Shadehill, S. Dak., when low-quality irrigation water was used.

was still increasing when the experiment was terminated in 1958. Neither yields of alfalfa hay nor rates of water intake was influenced by the buildup of sodium in the soil.

It was concluded that any additional effects of the high residual content of sodium carbonate in the water on increasing sodium absorption in the soil may be counter-balanced by other factors. These factors include rainfall and the solution of calcium mineral in the soil.

COMPARATIVE YIELDS OF DRYLAND AND IRRIGATED CROPS IN THE NORTHERN GREAT PLAINS

Benefits derived from irrigating crops in arid regions are self-evident. In the subhumid climate of the Great Plains, a successful dryland agricultural economy has been developed under limited rainfall conditions. When irrigation water is applied to crops in addition to rainfall received, yields are almost always increased (*1*). Whether the increase in production warrants conversion from dryland to irrigated agriculture is a matter for consideration by both the economist and the farmer.

Data compiled by Haise (*18*), although not strictly comparable in all cases, give some indications of the relative magnitude of dryland and irrigated crop yields (table 7). Many of the locations reported are in the higher rainfall areas of the Great Plains; hence, the percentage increases from irrigation are not so great as would be expected in the more arid regions. Also, certain data represent only 2 years' results. The relatively low percentage increase in the production of irrigated spring wheat at Redfield, S. Dak., is in accord with results obtained at Upham, N. Dak. Spring wheat grown with adequate fertility and irrigation seldom yielded more than 40 bushels. Barley and oats yields obtained under irrigation at Redfield and Upham have been lower than those obtained at Huntley, Mont. Factors limiting small-grain production under irrigation in this area of the Great Plains are not fully understood.

Table 7.—*Average annual yield of dryland and irrigated crops produced at various locations in the northern Great Plains for years indicated*

Crop and location [1]	Dryland		Irrigated		Increase
	Years	Yield	Years	Yield	
SPRING WHEAT		*Bushels*		*Bushels*	*Percent*
Huntley	1913–53	13.6	1929–37	53.0	290
Redfield	1949–53	25.6	1949–53	33.9	32
BARLEY					
Huntley	1913–53	11.7	1938–53	78.0	566
Newell	1909–55	21.1	----------	49.0	132
Redfield	1949–53	28.0	1939–43	38.6	38
Mandan	1915–53	21.9	1951–52	53.0	142
CORN					
Huntley	1913–53	14.4	1929–53	78.0	442
Redfield	1949–53	42.2	1949–53	90.5	114
Upham	1956–57	39.2	1956–57	62.2	59
Newell	1909–55	24.7	----------	52.0	110
Mandan	1915–53	26.1	1952	85.5	228
OATS					
Huntley	1913–53	29.4	1929–53	106.0	260
Newell	1909–55	26.7	----------	66.0	147
Redfield	1949–53	37.6	1949–53	58.0	54
Mandan	1915–53	37.2	1951–52	91.0	145
FLAX					
Huntley	1913–51	6.9	1912–36	24.0	248
Newell	1909–55	6.5	----------	14.0	115
ALFALFA		*Tons*		*Tons*	
Redfield	1950–53	2.71	1950–53	5.05	86
Newell	1909–55	.80	----------	4.60	475
ALFALFA-BROME					
Huron	1950–52	2.0	1949–51	3.52	76
Upham (pasture)	1955–56	1.08	1955–56	2.25	108
(hay)	1955–56	1.55	1955–56	3.51	126
POTATOES					
Mandan	1915–53	133.0	1951–52	448.0	236

[1] Huntley, Mont.; Redfield, Newell, and Huron, S. Dak.; and Mandan and Upham, N. Dak.

SOIL-MANAGEMENT STUDIES WITH VARIOUS CROPS

The principal experimental results of the soil-management studies with the various crops are summarized by crops in the following sections. Yields given are the average for at least three plots but often four were used. **All yields and rates of application of fertilizer are for 1 acre, unless otherwise specified.** In obtaining yields from rows or sample areas, adequate guard rows or areas were allowed for. Methods used for analyses of soil and plant material for chemical contents were standard methods used in most laboratories. Whenever differences in yield or chemical composition are mentioned, these differences were found to be significant by accepted statistical procedures. Corn-grain yields are presented on a 15-percent moisture basis. Irrigation of all plots was accomplished by gravity methods.

Alfalfa

Alfalfa hay did not respond to phosphorus at Mandan or Bowbells, but small responses were measured at Redfield and Upham. At both Redfield and Upham the estimated phosphorus requirement for a 6-year rotation (barley-alfalfa-alfalfa-alfalfa-corn-potatoes) was drilled to a depth of 3 or 4 inches just before the alfalfa was planted with the barley. Hay yields show that treble superphosphate applied at a rate of 100 pounds of P_2O_5 was a good rate (table 8). Response to applied phosphorus was greatest on areas where some of the subsoil had been exposed by land leveling (fig. 4).

In these studies considerable residual benefits from phosphorus fertilizer were measured. Yield response to phosphorus 3 years after application

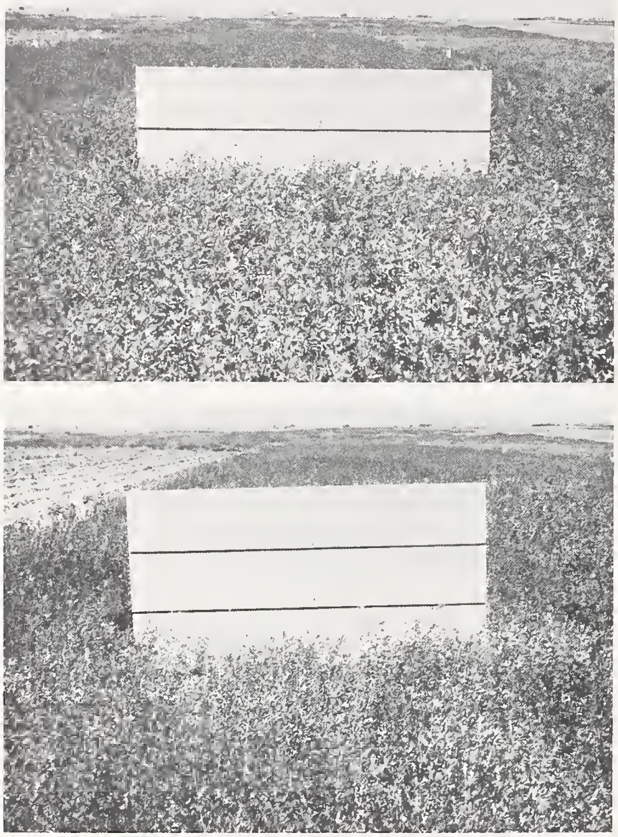

FIGURE 4.—Phosphorus fertilizer increased the growth of first cutting of alfalfa on a subsoil exposed by land leveling at Upham, N. Dak., in 1957. Bottom—no fertilizer; top—50 pounds of P_2O_5 per acre.

was about the same as during the first and second years. Adding sufficient phosphorus at seeding time to supply the needs of the alfalfa for the 3 years in the rotation proved to be a good practice.

Phosphorus fertilization applied at the rate of 300 pounds per acre on barley the year alfalfa

TABLE 8.—*Effect of phosphorus fertilization on the yield of alfalfa hay in irrigated rotations at Upham, N. Dak., and Redfield, S. Dak.*[1]

P_2O_5 per acre, pounds [2]	Year sampled: 1954	1955	1956	1957	Average, all years
	UPHAM				
	Tons	*Tons*	*Tons*	*Tons*	*Tons*
0	4. 73	4. 26	3. 02	4. 34	4. 09
100	5. 11	4. 28	3. 96	5. 51	4. 72
150	5. 35	4. 93	4. 12	5. 45	4. 96
300	5. 40	4. 87	4. 09	6. 02	5. 10
	REDFIELD				
0	4. 68	4. 17	------	------	4. 42
83	5. 45	3. 92	------	------	4. 68
125	5. 45	3. 51	------	------	4. 48
250	5. 43	4. 60	------	------	5. 02

[1] Yields on 12-percent moisture basis.
[2] Phosphorus was applied just before seeding.

was seeded did not appreciably increase the protein concentration of alfalfa hay at Upham (table 9). However, owing to the effect of phosphorus on increasing alfalfa hay yields, the total protein production was increased. It is expected that similar yields of protein would have been obtained if only 100 to 150 pounds of P_2O_5 had been applied. Phosphorus fertilization was very effective in increasing both the phosphorus concentration in and the total phosphorus absorbed by the alfalfa. At Redfield, phosphorus fertilization did not increase the concentration of protein in the alfalfa but did increase the concentration of the phosphorus.

In an irrigation experiment at Bowbells in 1951, 150 pounds of P_2O_5 per acre increased alfalfa hay yields at all levels of applied water (fig. 5). For

TABLE 9.—*Effect of phosphorus fertilization on the nutrient content of alfalfa at Upham, N. Dak. Average values for 1954–57*[1]

Fertilizer applied [2]	Hay yield per acre [3]	Protein content	Total protein per acre	Phosphorus content	Total phosphorus per acre
	Tons	*Percent*	*Pounds*	*Percent*	*Pounds*
None	4. 3	19. 8	232	0. 214	15. 7
Phosphorus	5. 5	20. 3	304	. 311	29. 3

[1] Data shown are average values for first, second, and third growing years of alfalfa.
[2] Generally 300 pounds of P_2O_5 per acre applied on barley the year alfalfa was seeded.
[3] 12-percent moisture basis.

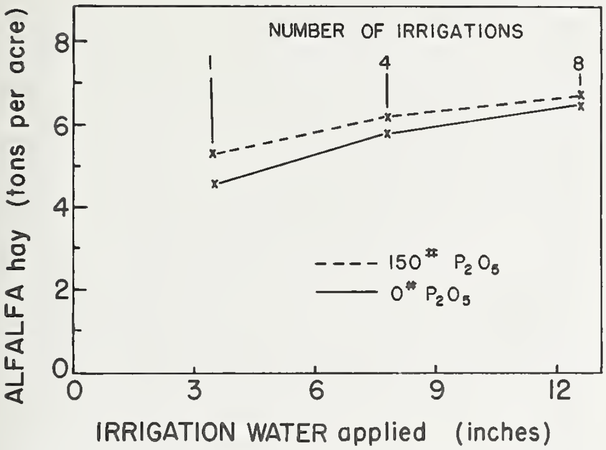

FIGURE 5.—Yields of alfalfa hay produced when different amounts of irrigation water were applied with and without phosphorus fertilizer at Bowbells, N. Dak. (Yields reported on a 12-percent moisture basis.)

the phosphated plot receiving 3.5 inches of water in one irrigation, the alfalfa yield was 5.3 tons as compared with 6.2 tons on the plot receiving 7.9 inches of water in four irrigations. The yield on the plot receiving 12.6 inches in eight irrigations was only 0.4 ton higher than on the plot receiving 7.9 inches. Recommendations for application of a specific amount of irrigation water are difficult to make in an area where rainfall varies greatly from year to year. In most seasons alfalfa will require two or three good irrigations for maximum production.

Yields of a deep-rooted crop like alfalfa can be considerably influenced by a high water table. In an irrigated alfalfa study at Mandan in 1952, a low-moisture treatment promoted good growth even though the surface soil was dry. In a pit dug adjacent to the plot area, the water table was 7 feet below the soil surface and the "capillary fringe" about 3 feet (fig. 6). Alfalfa roots growing into the capillary fringe accounted for the good top growth in what appeared to be very dry soil.

In areas where the water table is high, it is possible for crops like alfalfa to receive most of the needed water from the water table. Damage from salt movement into the root zone is a hazard in these areas. In a Montana experiment, irrigation treatments that allowed alfalfa to take the needed water from the moist soil layer above the water table had appreciable salt accumulated in the 3- to 7-foot layer after a short time (*5*).

FIGURE 6.—Alfalfa root development on low-moisture plots showing extension of roots into moist soil above the water table at Mandan, N. Dak., in 1952.

Treatments receiving more than one irrigation did not show a buildup of salt in the soil profile.

When alfalfa was seeded alone at Redfield, stands were more vigorous than those seeded with barley. However, satisfactory stands have been established by seeding the alfalfa with barley as a companion crop when small amounts of nitrogen fertilizer were used on the barley. Poor alfalfa stands were obtained as a result of too much shading from a barley companion crop fertilized with nitrogen at the rate of 60 pounds per acre.

At both Mandan and Upham, Ladak and Rhizoma were the highest yielding varieties. Grimm and Ranger made quicker recovery after harvest but had lower yields.

Corn

Corn is one of the most important grain crops in South Dakota and southern North Dakota. In

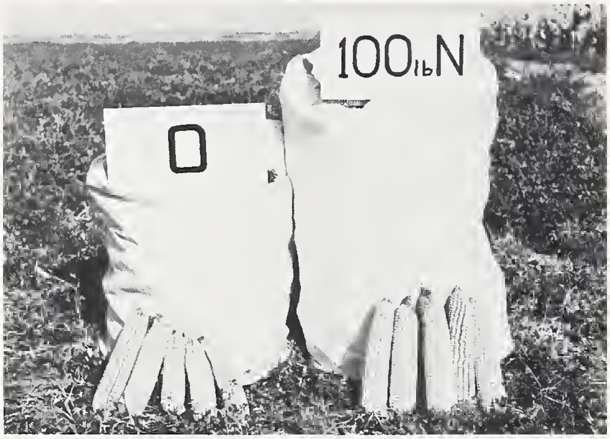

FIGURE 7.—Relative yield and ear quality were increased by nitrogen fertilization in a nonlegume irrigated rotation at Redfield, S. Dak., in 1951.

the central and northern part of North Dakota corn is grown only as a silage crop, since in most years it does not mature enough to be cribbed.

The hybrids Nodak 301 and Wisconsin 270 and 279 gave the highest grain yields in tests at Mandan. Nodak 301 was used in all experimental work at Upham.

In a South Dakota study, irrigation hastened development of corn in most years (*10*, *12*). This allowed the use of slightly longer season hybrids than those adapted for dryland conditions. Sokota 220, 270, and 400, as well as Pioneer 377A, were the best hybrids in the Redfield tests.

Nitrogen fertilizer has generally increased corn yields at all locations (*2*, *10*, *14*, *28*) (fig. 7).

In a rotation at Upham, which did not include a legume, corn forage yields were 4.1, 5.5, 6.2, and 6.3 tons for the 0-, 40-, 80-, and 120-pound rates, respectively (fig. 8). In some years there was considerable difference in growth at the various rates of nitrogen (fig. 9). At Redfield the first treatment of 40 pounds of nitrogen increased corn yields about 9 bushels, with the second 40-pound increment increasing yields about 7 bushels. (Corn-grain yields in this publication are expressed on a 15-percent moisture basis.)

In experiments at Upham and Redfield nitrogen fertilizer gave only small yield increases when applied to corn grown on land that had previously been in alfalfa. At Upham, forage yields in the legume rotation were 6.2, 6.7, 6.9, and 6.8 tons for 0-, 40-, 80-, and 120-pound rates of nitrogen, re-

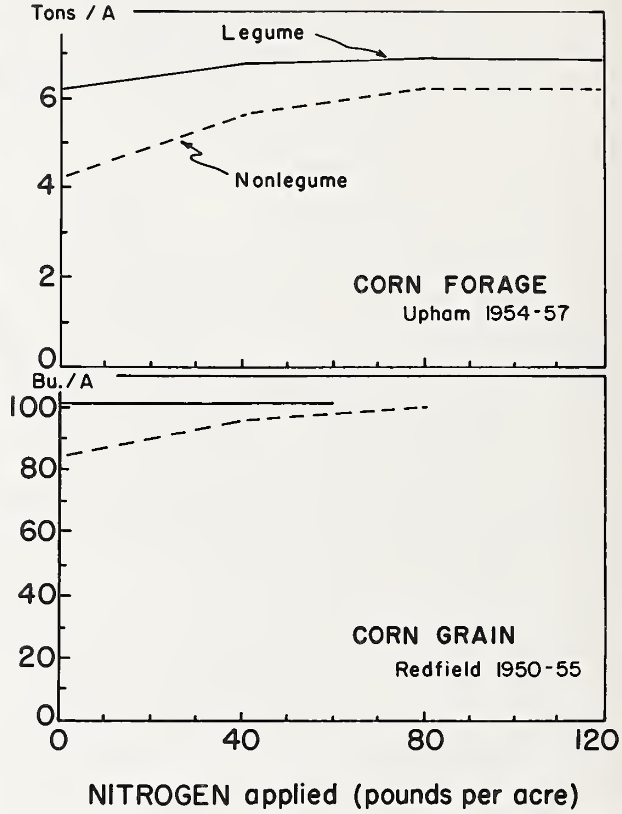

FIGURE 8.—Corn-yield response to nitrogen was greatest in rotations that did not include a legume at Upham, N. Dak., and Redfield, S. Dak. (50 pounds of P_2O_5 per acre was added to all treatments. Yields reported on a 12-percent moisture basis.)

FIGURE 9.—Nitrogen fertilizer increased the height and yield of corn in a nonlegume rotation at Upham, N. Dak., in 1956. Left—no nitrogen; right—80 pounds of nitrogen per acre.

spectively (fig. 8). Grain yields at Redfield were the same for the 0- and 60-pound rates.

In most of the experiments conducted in the area with crops other than alfalfa, phosphorus fertilizer did not increase yields when applied alone. At Upham it decreased yields in the nonlegume rotation but increased them in the legume rotation. Phosphorus applied with nitrogen increased yields in both rotation systems. However, phosphorus was not so effective as nitrogen in increasing yields. Annual application rates equivalent to 25 pounds of P_2O_5 per acre were as effective as the 50-pound rate.

Starter applications of nitrogen and phosphorus had no effect on corn yields at Mandan. Splitting the nitrogen treatments into two applications gave yields that were similar to those for the single application. Side-dressing nitrogen late in June did not affect yields or the nitrogen content of leaves at silking when compared to the treatment that received the same amount of nitrogen at planting time. Nitrogen content of leaves is a measure of the adequacy of nitrogen, and is closely related to yield. Corn yields in a Nebraska test were not appreciably influenced by splitting the nitrogen application (*29*).

Potassium did not give any yield increase in the many fertilization studies in which it was included. A zinc deficiency in corn was first observed at Upham in 1953 on an area from which the surface soil had been removed to facilitate gravity irrigation. The deficiency was corrected by applying 15 pounds of zinc or 20 tons of manure.

In several studies, nitrogen fertilizer increased yields under irrigation, but not under dryland. At Upham, nitrogen rates increased both forage and grain yields when a total of 9 inches of water was applied in three irrigations, but no response to nitrogen was measured under dryland (fig. 10). Nitrogen fertilizer, at the rate of 120 pounds per acre, increased both corn forage and grain production 35 percent on the irrigated plots.

At Redfield, drill-planted corn, spaced 9 inches apart in 36-inch rows, yielded more than hill-planted corn spaced 36 inches apart in 36-inch rows, with four plants per hill (fig. 11). Total plant population was 19,360 plants per acre in both plantings. On the nonfertilized treatments, drill-planted corn yielded as much as 18 bushels more than hill-planted. At the 80-pound nitrogen rate, a difference of only 5 bushels between the two planting methods was measured.

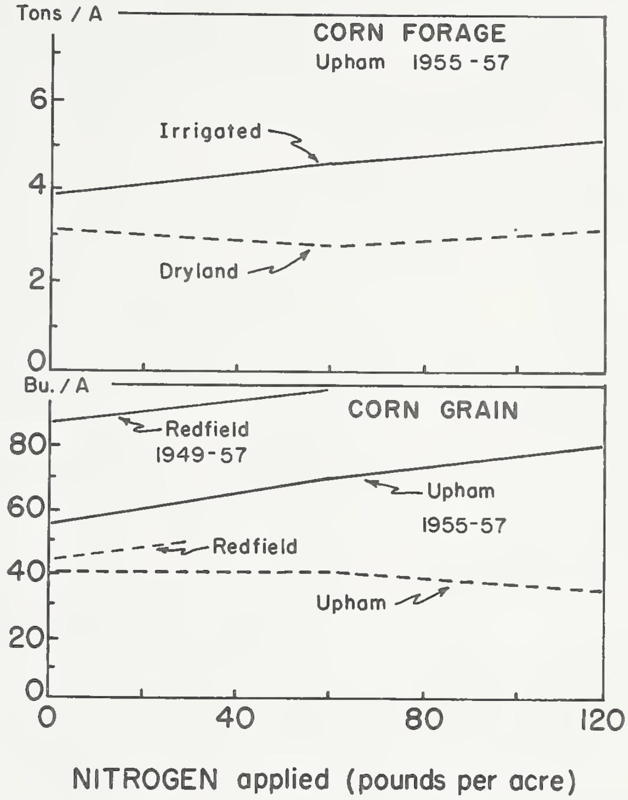

FIGURE 10.—Irrigation and nitrogen fertilizer affect corn yields in nonlegume rotations at Upham, N. Dak., and Redfield, S. Dak. (Yields reported on a 12-percent moisture basis.)

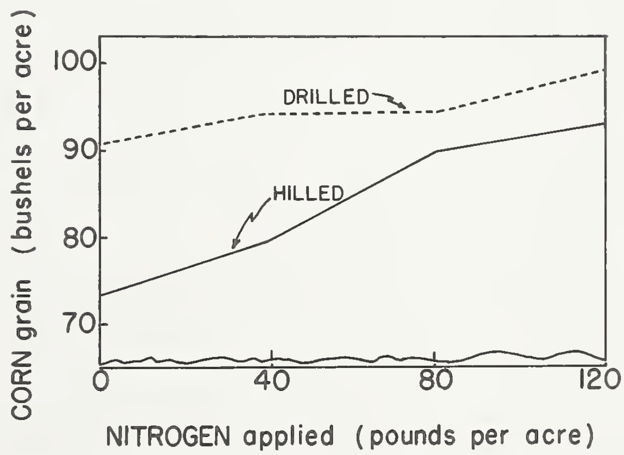

FIGURE 11.—Drill-planted corn yielded more than hill-planted for several nitrogen fertilizer rates at Redfield, S. Dak., 1954–55. Plant density was 19,360 plants per acre.

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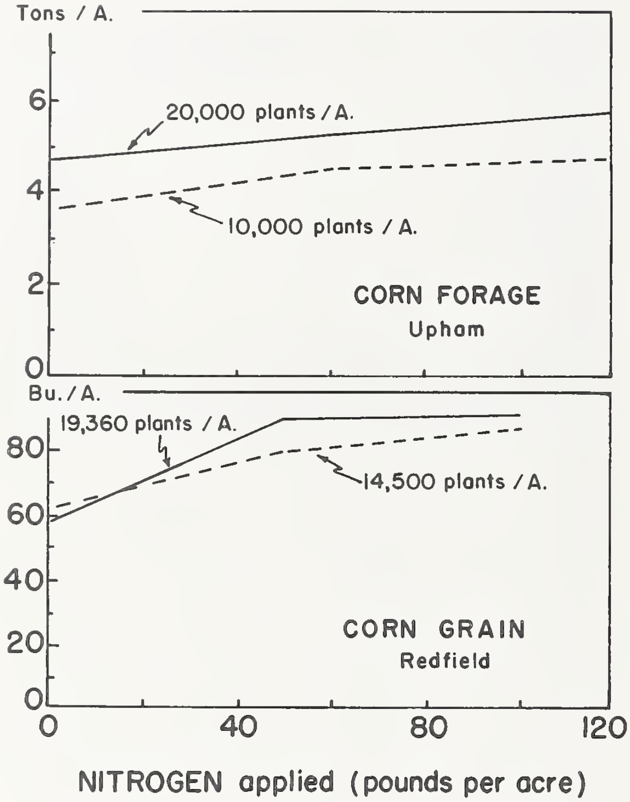

FIGURE 12.—Corn yields were increased by increasing plant density and adding nitrogen fertilizer at Upham, N. Dak., and Redfield, S. Dak. (Yields reported on a 12-percent moisture basis.)

A study at Mandan, using the same plant spacings, showed that drilled corn was 12 to 16 inches taller than hilled corn early in the season but at harvest the yields were the same. Results from these two locations suggest that competition for plant food caused plant growth to be different in the two planting systems.

Plant-density experiments at Upham showed that 20,000 plants per acre yielded more forage than 10,000 plants per acre (fig. 12).[3] Differences in yield were greater for high rates of nitrogen fertilization. In some years, yields at Upham were increased as much as 30 percent by increasing the plant population.

Results at Redfield showed (fig. 12) that populations of 19,000 plants per acre combined with adequate soil fertility are essential in order to obtain satisfactory corn yields. Lower populations yielded slightly more than the higher populations when no nitrogen was applied.

The addition of 80 pounds of nitrogen to corn in a nonlegume rotation increased the protein concentration 1.5 and 2.1 percent at Upham and Redfield, respectively (table 10). These values are much higher than the corresponding increases of 0.5 and 1.0 percent that occurred in the legume rotations.

TABLE 10.—*Mean protein concentrations in corn grain for several fertilizer treatments at Upham, N. Dak., and Redfield, S. Dak.*

$N-P_2O_5$, pounds per acre	Protein [1] in corn grain			
	Upham rotation [2]		Redfield rotation [3]	
	Nonlegume	Legume	Nonlegume	Legume
	Percent	*Percent*	*Percent*	*Percent*
0–0	10.9	11.9	8.4	10.0
0–50	10.2	11.8	8.7	11.1
80–0	12.4	12.4	10.5	11.0
80–50	12.0	11.9	9.7	11.2

[1] Percent protein=percent nitrogen ×6.25.
[2] Means of 4 years' data (1954–57).
[3] Means of 2 years' data (1954–55).

The total protein content of corn grain increased in the nonlegume rotation at both locations (fig. 13) following the addition of 80 pounds of nitrogen. Increases in protein were 100 pounds at Upham and 300 pounds at Redfield. Increased yields of protein due to the application of 80 pounds of nitrogen per acre were much smaller in the legume than in the nonlegume rotation at both locations.

In the nonlegume rotation at Upham (fig. 13), the protein removed in corn grain and forage was reduced by the addition of phosphorus alone. At Redfield added phosphorus did not appreciably decrease the total protein removed in the grain.

The addition of phosphorus in the presence of added nitrogen resulted in increased total protein removed in the grain in the nonlegume rotation at Upham. This was due to the effect of the phosphorus in increasing yields, rather than in increasing protein concentrations. At Redfield the total protein was reduced by this treatment, because the protein concentration was lowered whereas the yield was not affected.

At Upham the amount of nitrogen (or protein) removed by corn plants was more in all treat-

[3] Plant spacings were 9 and 18 inches in corn rows spaced 34 inches apart.

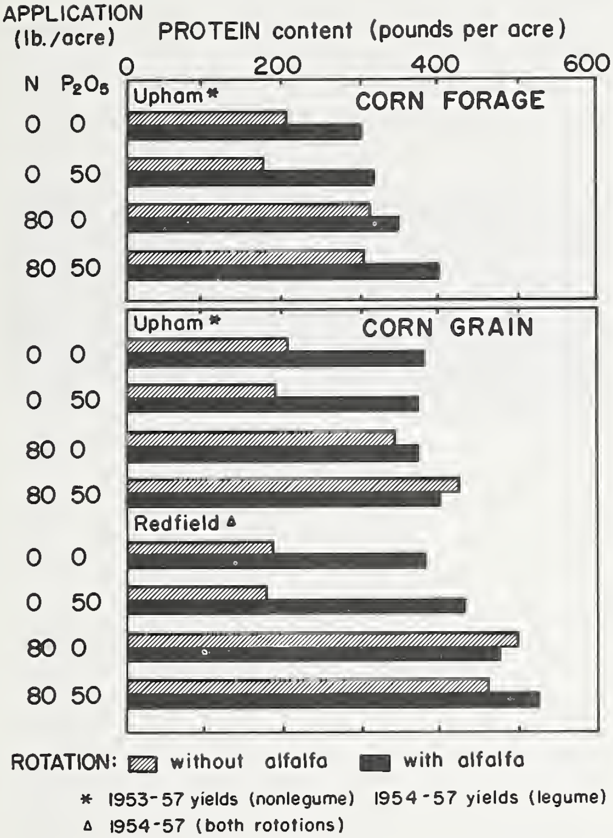

FIGURE 13.—Protein content of corn grain and of corn forage were increased by nitrogen fertilizer and alfalfa at Upham, N. Dak., and Redfield, S. Dak.

ments than that applied by fertilization (table 11). This emphasizes the effect of corn as a soil-nitrogen-depleting crop. The nitrogen absorbed was greater in the legume rotation than in the nonlegume rotation for all fertilizer treatments. These data also show that the protein content of a corn crop can be increased by the use of nitrogen fertilizer.

Potatoes

Potato varieties responded differently to the same nitrogen-fertilizer treatment at Redfield in 1953. Yield increases from applications of 60 pounds of nitrogen ranged from 49 to 110 bushels per acre, depending on the variety (fig. 14). At the 120- and 180-pound nitrogen rates, Lasoda yielded approximately 150 bushels per acre more than Early Ohio. Phosphorus applied with nitrogen gave little additional yield response in this experiment. These results show the importance

TABLE 11.—*Total nitrogen absorbed per acre in corn plants (kernels, cobs, and stalks) for two rotations at Upham, N. Dak.*

Average N-P_2O_5 per year per acre, pounds	Average nitrogen per acre in forage, 1954–57 [1]: Nonlegume rotation	Legume rotation
	Pounds	*Pounds*
0–0	77	109
0–50	59	111
40–50 [2]	86	142
80–0	106	114
80–50	117	128
120–50 [2]	133	146

[1] To obtain protein, multiply by 6.25.
[2] 1956 and 1957 data, only.

of selecting potato varieties capable of utilizing applied nitrogen if maximum yields are to be obtained.

No potato-variety tests were conducted at any of the North Dakota experimental sites. Pontiac was used in all the potato experimental work reported from Mandan, Bowbells, and Upham.

Maximum production of potatoes at Mandan, Bowbells, and Upham required nitrogen fertilizer at rates of 80 to 160 pounds per acre (table 12 and fig. 15). Phosphorus applied with nitrogen gave yield increases of 60 to 65 bushels at Bowbells, but none at Mandan. At both locations, applying all of the nitrogen at planting time produced

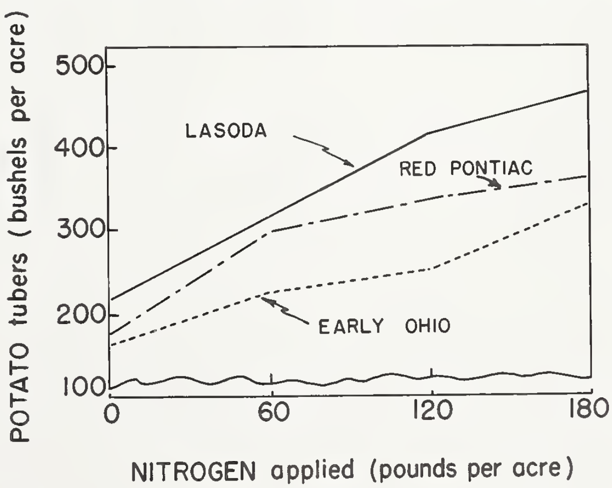

FIGURE 14.—Potato varieties differed in their response to nitrogen fertilizer in a test at Redfield, S. Dak., in 1953. All treatments received 50 pounds of P_2O_5 per acre.

FIGURE 15.—A field of Pontiac potatoes at the Deep River Development Farm, Upham, N. Dak. Field received 80 pounds of N and 80 pounds of P_2O_5 per acre. (U.S. Bureau of Reclamation photo.)

FIGURE 16.—Response of potatoes to per acre applications of 50 pounds of P_2O_5 (left) and 120 pounds of N plus 25 pounds of P_2O_5 (right) at Upham, N. Dak. (Note height of plant tops against the white stakes in the foreground.)

yields equal to those obtained by applying half of the nitrogen at planting time and the other half when the potatoes were in bloom.

Nitrogen fertilizer applied at rates of 60 to 120 pounds per acre was necessary for good yields at Upham in the nonlegume rotation (figs. 16 and17),

TABLE 12.—*Potato yields per acre at different nitrogen and phosphorus levels at Bowbells and Mandan, N. Dak.*

$N-P_2O_5$ per acre, pounds	Bowbells (1950)	Bowbells (1951)	Mandan (1950)
	Bushels	*Bushels*	*Bushels*
0–0	280	334	440
50–0		358	
80–0	330		670
0–30		345	
50–30		423	
100–30		472	
40–100	320		620
80–100	390		650
160–100	370		700
160–100 [1]	390		670

[1] Nitrogen split into two 80-pound applications.

whereas in the legume rotation, 60 pounds of nitrogen was adequate (fig. 17). Fifty pounds of P_2O_5 was needed with the nitrogen in order to obtain maximum yields. No increases in the percentage of No. 1 potatoes were obtained by fertilization.

In 1955 high rates of nitrogen fertilizer decreased potato yields in the legume rotation at Upham. The spring of 1955 was warmer than usual, with mean April and May temperatures of 47° and 57°F., respectively. Conditions were probably favorable for the mineralization of soil nitrogen to nitrates. In consequence, the available nitrogen in the highly fertilized soils in the legume rotation was extremely high. Some of the decrease in yield resulting from the high-nitrogen treatments was probably due to delayed maturity, but there were other possible causes. Warm springs are unusual in the area, and the general recommendation would be to apply nitrogen to obtain maximum potato yields under irrigation.

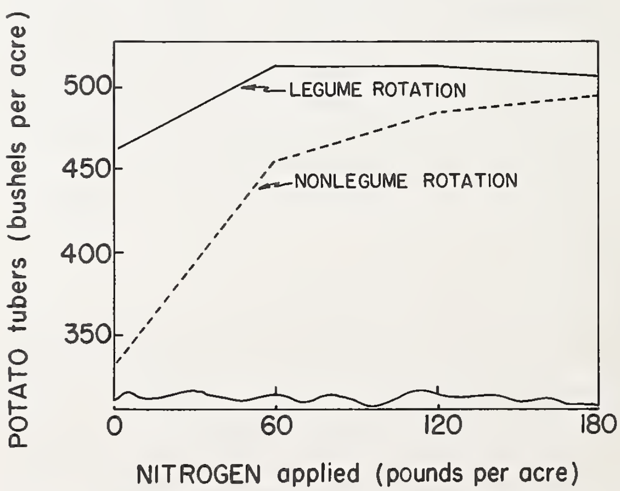

FIGURE 17.—Nitrogen fertilizer increased potato yields most in the rotation that did not include alfalfa at Upham, N. Dak., 1955–57. (Phosphorus was added to all plots.)

The addition of nitrogen fertilizer increased the relative availability of banded fertilizer phosphorus to potatoes. At Bowbells, 8.1 percent of the plant phosphorus in the tubers was derived from the fertilizer when no nitrogen was added, and 24.4 percent when nitrogen was added (*17*). This was probably related to an effect of nitrogen on increasing growth of tops and tubers in addition to decreasing soil pH, especially in the vicinity of the phosphorus fertilizer bands. Nitrogen not only is important as a nutrient element, but nitrogen fertilization also increases the absorption of applied phosphorus fertilizer by potatoes.

Experiments at Upham have shown that potatoes spaced 8 inches apart in 34-inch rows yielded more than those spaced 12 inches apart. At Redfield, planting as close as 6 inches apart within the row decreased the yields despite large applications of water and nitrogen and phosphorus fertilizers. This close spacing also increased the number of culls.

Yields were similar for the medium- and high-moisture treatments in an experiment conducted at Mandan in 1953. In the medium-moisture level the plots were irrigated when 60 to 70 percent of the available water was depleted to a depth of 4 feet. These plots received two irrigations totaling 4 inches of water during the season. In the wet treatment, 9 inches of water was applied in five irrigations in order to have more than 50 percent of the available soil water remaining in the 4-foot profile. Rainfall in June, July, and August totaled 10½ inches, which was 3 inches above normal.

No experiments have been conducted to determine the relationship between potato quality and soil moisture tensions (the force with which water is held). However, other workers have shown that the proportion of U.S. No. 1 potatoes is greater when grown at higher moisture levels (*30*)

Sugar Beets

Experiments on several development farms indicate that sugar beets can be grown successfully with irrigation in all parts of the area. Maximum yields of 28.8, 26.1, and 17.0 tons have been obtained at Mandan, Redfield, and Bowbells, respectively.

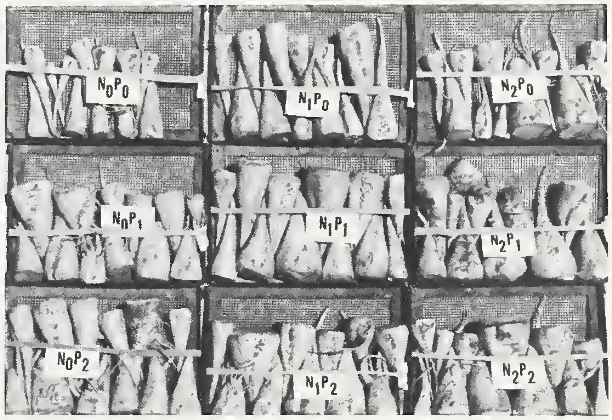

FIGURE 18.—Both nitrogen and phosphorus were needed for maximum yields of sugar beet roots on an area with some of the surface soil removed at Mandan, N. Dak.

Nitrogen fertilizer had no effect on sugar beet yields on the normal topsoil at Mandan in 1951. Phosphorus fertilization increased root and top growth early in the season, but these responses did not persist until harvesttime. Where some of the surface soil had been removed, both nitrogen and phosphorus were needed for maximum yields (fig. 18).

In 1952, on treatments receiving 20 pounds of P_2O_5 per acre 3 inches below the seed, plants at thinning time were larger than those on the treatments receiving the same rate of phosphorus broadcasted. However, yields at harvest were similar for all fertilizer treatments. Results from Montana experiments show broadcasting and plowing under phosphorus gave higher yields than banding (*22*).

At Bowbells, both nitrogen and phosphorus were effective in increasing yields of sugar beet tops and roots. Placement of some of the phosphorus fertilizer with the seed increased the weights of tops at thinning for sugar beets which were planted on May 1 or May 26, but was no better than sidedressing for beets planted on April 16 (table 13). For the beets planted on May 1, yields of roots at thinning were higher when some of the phosphorus was placed with the seed, but this was not true of the other two planting dates. At harvest, root yields and sugar contents were similar whether all the phosphorus fertilizer was sidedressed or some was placed with the seed. Yields decreased a ton per acre for every week later than April 16 that the beets were planted,

TABLE 13.—*Effect of date of planting and placement of phosphorus fertilizer on weight and sugar content of sugar beets at Bowbells, N. Dak.*

P_2O_5 per acre, pounds	TOPS			BEETS		
	Dry weight per plant at thinning			Harvest data per acre when planted		
	Planted—Apr. 16; thinned—June 16	Planted—May 1; thinned—June 24	Planted—May 26; thinned—July 1	Apr. 16	May 1	May 26
	Grams	*Grams*	*Grams*	*Tons*	*Tons*	*Tons*
50-sidedressed	1. 22	0. 78	0. 16	16. 2	14. 0	9. 8
30-sidedressed, 20-with seed	1. 13	. 96	. 25	16. 2	14. 2	10. 4
	ROOTS			SUGAR		
50-sidedressed	0. 17	0. 07	0. 02	2. 94	2. 47	1. 68
30-sidedressed, 20-with seed	. 16	. 10	. 02	2. 86	2. 56	1. 82

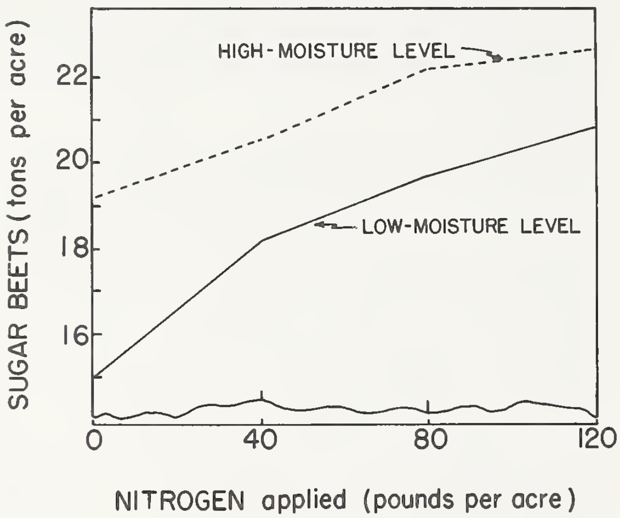

FIGURE 19.—Irrigation and nitrogen fertilizer increased sugar beet yields at Redfield, S. Dak.

emphasizing the need to plant as early as possible for maximum production. Application of boron had no effect on weights of tops or roots at thinning, or on harvest yields or sugar content of the beets. The average sugar content was 17.8 percent.

On an exposed subsoil at Bowbells (*19*), per acre applications of 100 pounds of nitrogen and 100 pounds of P_2O_5 increased sugar beet yields from 4.2 to 12.6 tons per acre. Synthetic soil conditioners improved the physical properties of the soil, but also tended to decrease the sugar beet yields. Manure, applied at the rate of 20 tons per acre, had little effect on the physical properties of the soil.

Sugar beets irrigated 10 times yielded more than those irrigated 4 times at Redfield (fig. 19). At both moisture levels, nitrogen was very effective in increasing yields. Phosphorus additions did not increase yields at the low-moisture level, but did at the high-moisture level. Both nitrogen and phosphorus were necessary for good growth of beet tops. Applied nitrogen decreased the root-top ratio in both moisture regimes. Phosphorus increased the root-top ratio, but only at the high-moisture level. The sugar content averaged 18.5 percent, and was not affected by moisture level or by the application of nitrogen or phosphorus fertilizers.

In a sugar beet experiment at Upham in 1953, the nitrogen sources were ammonium nitrate, ammonium sulfate, sodium nitrate, and nitric acid (*17*). In banded treatments, the nitrogen sources were placed 3 inches to the side of and 3 inches below the seed. The nitrogen was banded with the concentrated superphosphate in some instances, and on the opposite side of the plants from the phosphorus band in others. On some plots ammonium sulfate was also spread on the soil surface and disked in to a depth of approximately 2 to 3 inches. Although the beet yields increased owing to the application of nitrogen fertilizer, there was

no consistent effect of form or placement of nitrogen fertilizer on these yields.

As with the nitrogen, the phosphorus was banded in some plots, and broadcast and disked in on others. While the beet yields generally increased because of the addition of phosphorus, there was no consistent effect of method of phosphorus placement on these yields.

At Bowbells, Redfield, and Upham, the addition of nitrogen fertilizer increased the relative availability of banded phosphorus fertilizer to plants (*13*, *17*). For example, at Upham in recently matured sugar beet leaves sampled on August 12, 47 percent of the plant phosphorus was derived from the fertilizer when no nitrogen was added. When nitrogen was added, 60 percent of the plant phosphorus in similarly sampled leaves was derived from the fertilizer. This phenomenon was probably related to an effect of nitrogen on increasing growth of tops and roots, as well as to an effect of nitrogen fertilizers on decreasing soil pH, especially in the vicinity of the phosphorus fertilizer bands. A similar effect with potatoes has been mentioned in the preceding section.

Wheat

At Redfield, nitrogen has consistently increased wheat yields in the legume and especially in the nonlegume rotation (table 14). Treatments that received nitrogen fertilizers yielded about 40 bushels in both rotations.

TABLE 14.—*Effect of nitrogen fertilizer on irrigated wheat yields at Redfield, S. Dak., 1949–55*

Fertilizer and rate of application per acre	Nonlegume rotation [1]	Legume rotation [2]
	Bushels	*Bushels*
P_2O_5, 100 pounds	26. 5	31. 8
N, 60 pounds + P_2O_5, 100 pounds	38. 3	41. 7
	Percent	*Percent*
Increase from N fertilization	44. 5	31. 1

[1] Wheat-corn.
[2] Wheat-alfalfa-alfalfa-corn.

Sixteen bread and durum wheat varieties were tested at Upham from 1953 to 1956. Durums yielded about 10 percent more than the bread wheats. Langdon ranked first, with a yield of 48 bushels per acre followed by Ramsey with a yield of 45 bushels. Selkirk was the higest yielding bread wheat, with a yield of 31 bushels followed by Conley with a yield of 28 bushels. All have resistance to leaf rust and to stem rust 15–B.

Generally, wheat in the northern part of the area has not benefited from irrigation to the degree that has been reported in the southern part. Undoubtedly, rust partially accounts for this difference. Development of new rust-resistant varieties will allow wheat to have a place under irrigation. Also, the natural precipitation may be more effective in the northern part because of less evaporation.

Barley

Nitrogen fertilizer applied to barley at Upham and Redfield at the rate of 40 pounds per acre resulted in maximum yield increases of 14 and 16 bushels, respectively (fig. 20). The addition of 60

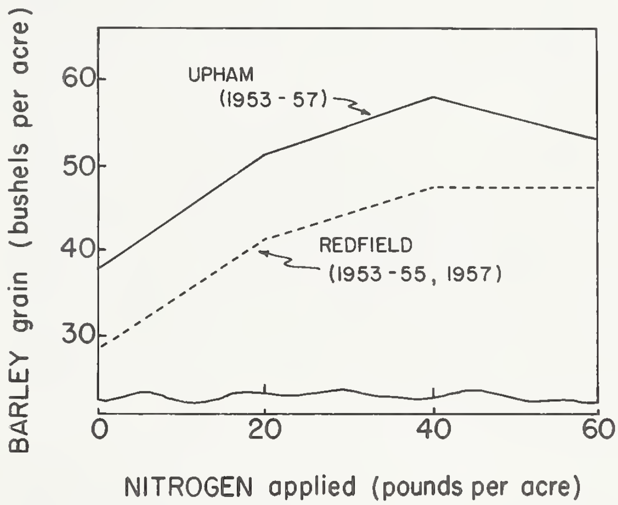

FIGURE 20.—Nitrogen fertilizer increased yields of barley grain at Upham, N. Dak., and Redfield, S. Dak., in nonlegume rotations. (Phosphorus was added to all plots.)

pounds of nitrogen at Upham caused lodging, which decreased yields and test weights. For plots that did not lodge, test weights were similar regardless of fertilized treatment.

In the legume rotations at both locations yield responses to nitrogen were small, but lodging occurred where 40- to 60-pound nitrogen rates were used. Here again, test weights were lower on the lodged plots. Yield reductions due to lodging were greater on land where alfalfa had recently been grown.

In general, phosphorus applications without nitrogen gave little or no response at most lo-

cations. Where nitrogen was supplied either in commercial fertilizers or by plowing the alfalfa under, phosphorus substantially increased yields. For example, 40 pounds of P_2O_5 at Mandan increased barley yields about 25 bushels per acre. Further additions were not beneficial. Responses to phosphorus at other locations generally were less and in some instances almost nil.

In barley-variety trials at Mandan and Bowbells, Vantage was the highest yielder. In a 3-year test at Mandan, Vantage yielded 75 bushels followed by Montcalm, a malting variety which yielded 71 bushels. At Bowbells, in a 2-year test, Vantage yielded 78 bushels followed by Tregal which yielded 72 bushels.

Husky yielded 62 bushels at Upham in a 3-year study, followed by Trebi which yielded 61 bushels. In this test the malting varieties, Montcalm and Traill, yielded about 10 percent less than the feed barleys mentioned above.

Oats

Vicland was the highest yielder in a 2-year study at Bowbells and Mandan, 107 and 122 bushels, respectively. Gopher and Ajax yielded over 100 bushels in both tests. Branch, Garry Selection, Exeter, and Rodney yielded 87.9, 85.7, 85.3, and 82.5 bushels, respectively, in a 3-year test at Upham. Crown rust and stem rusts have been a problem at this location.

Flax

An experiment conducted at Bowbells to determine the effect of row spacing on flax production, when grown at two nitrogen levels, showed that yields decreased as row spacings wider than 6 inches were used (fig. 21). Nitrogen fertilizer did not increase yields.

In variety trials at Mandan and Bowbells, B5128 outyielded eight other varieties; yields for 2 years of trials were 32 and 26 bushels, respectively. Redwood, Bison, and Dakota also gave good yields. At Upham, in a 4-year study, Redwood, Marine, Norland, and B5128 all yielded about 17.5 bushels. Yields at Bowbells and Upham were lower than those at Mandan. Diseases at Bowbells and Upham probably account for lower yields at these two locations.

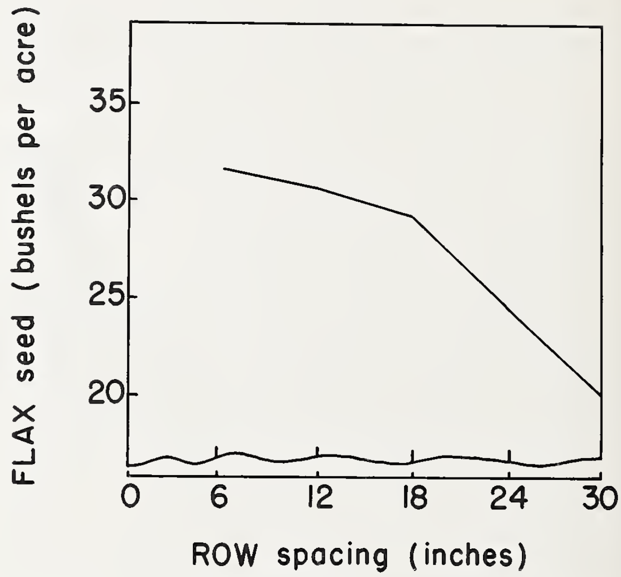

Figure 21.—Yields of flax at Bowbells, N. Dak., were markedly decreased when rows were spaced more than 18 inches apart.

Soybeans

In two experiments conducted at Redfield, soybean yields were 34, 53, and 30 bushels for the 9-, 18-, and 36-inch spacings, respectively. At all row spacings, soybeans were planted 3 inches apart in the row. This made a total of 116,000 plants per acre when the rows were spaced 18 inches apart.

Irrigation increased yields slightly in these experiments. Results showed that the moisture supply should be kept adequate throughout the development of the crop to insure maximum production.

Soybeans will be an important crop in the southern part of the area, but there are only a few varieties available now that will mature in the northern part. At Redfield, the varieties Ottawa, Mandarin, and Capital gave high yields and were most desirable for combining. Only Acme and two early-maturing varieties from Canada (051–318 and 051–322), matured enough for grain harvest in a Mandan study. All other varieties had soft beans in the top pods when frost came. At Mandan, difficulty was also encountered in establishing stands because of cold soils. The average yields at Redfield were about 35 bushels as compared with 30 bushels at Mandan.

Forage Crops

Irrigated forage crops research was conducted in North Dakota at Mandan, Bowbells, and Upham. Although some information is given below, a more complete discussion of these studies and data collected will be presented in a subsequent publication.

Grasses and Legumes for Hay and Pasture [4]

Many species and strains of grasses and legumes were tested for adaption, yield, growth characteristics, and chemical composition at Mandan, Bowbells, and Upham. After the most promising grasses and legumes were selected, combinations of them were established in mixed plantings to determine which species and mixtures offered the most promise for use in irrigated pastures.

All tests indicated that smooth bromegrass possessed the most desirable combination of characteristics for general irrigated pasture use. Yields were high, there was no winter injury, and forage quality was good. Recovery after harvest was somewhat slower than that of other species. Because of its many desirable characteristics, this species should be included in most irrigated pastures in the area.

Another high-producing grass in all tests was reed canarygrass. Local strains of this species were completely hardy. This grass also offers good possibilities for irrigated pastures. Orchardgrass showed excellent pasture qualities because of its high yield (up to 6 tons per acre on a 12-percent moisture basis, with 200 pounds of nitrogen applied annually), rapid recovery after harvest, and good forage quality. However, no strains were tested that were completely winter hardy. Avon was one of the most hardy strains. This test indicated that orchardgrass should probably be used in most pasture seedings, but always in mixture with other grasses that are completely hardy such as bromegrass. Most of the grasses commonly grown for dryland pastures were not sufficiently productive under irrigation to be considered satisfactory for pastures. Species that lacked sufficient hardiness to be of value for pasture were tall fescue and tall oatgrass.

[4] The forage work reported in this publication was conducted in the Agricultural Research Service by George Rogler and Russell Lorenz, of the Forage and Range Research Division, in cooperation with the Soil and Water Conservation Research Division.

The effect of row spacing and nitrogen fertilizer on forage yields of Russian wildrye has been studied for 4 years at Mandan (*25*). Nitrogen fertilizer markedly increased forage yields, especially after the first year. Response to annual increments of up to 400 pounds of nitrogen were obtained. Three row spacings—6, 18, and 36 inches—were used. The trend was toward slightly higher yields at the wider spacings, particularly after the first year.

Alfalfa was the most satisfactory legume tested for use under irrigation when grown either for hay or in irrigated pasture mixtures. It was high yielding, resistant to winter temperatures when properly managed, made rapid recovery after defoliation, was high in forage quality, and fixed large amounts of nitrogen. A large number of varieties were tested and all yielded approximately 6 tons.

Red clover was sufficiently hardy and productive for 2 to 3 years after seeding. This legume also offers promise in pasture mixtures of increasing the production of new stands. Ladino clover showed considerable winter injury but recovered rapidly and should also be considered for pasture use. Several birdsfoot-trefoil varieties were also tested. Good growth was obtained but yields were low compared with those of alfalfa. Establishment was slow, stands were reduced by disease, and nitrogen fixation was not sufficient for the grasses grown in the mixtures. Other legumes tested were alsike clover, white clover, strawberry clover, and cicer milkvetch.

Annual Forage Crops

Sorghums offer considerable promise as an irrigated annual crop. Six varieties were tested at Mandan during a 2-year period in comparison with two varieties of Sudan grass, two varieties of pearl millet, and rainbow flint corn. Early sumac was the highest producing sorghum, with a silage yield of 21.5 tons (70-percent moisture) in 1955 and 17.9 tons in 1956. Sweet Sudan yielded 14.3 tons of silage in 3-foot rows in 1955, and 13.2 tons in 6-inch rows. In comparison, the 1956 corn forage yield was 12.7 tons. Satisfactory stands were not obtained in 1955. Sixty pounds of nitrogen were applied annually during July to these plantings.

Twelve varieties of soybeans were tested for forage and bean yields at Mandan in 1955. For-

age yields of dry hay averaged 2.4 tons. Acme, yielding 32.9 bushels, was the only named variety that produced fully mature beans before frost.

Grass Seed Production

Yields of seed of seven grasses commonly grown in the area were high at Mandan during a 3-year period. Tall wheatgrass was the highest yielding species, with an average of 769 pounds of seed. Nitrogen fertilization did not affect seed yields, but did increase forage yields. Forage yields (12-percent moisture) ranged from slightly over 2 tons to over 6 tons at the time of seed harvest.

In another more complete test at Mandan with crested wheatgrass, 3-year average seed yields were 665 pounds. There was no significant response in seed yields for this short period from annual applications of nitrogen up to 200 pounds. Forage yields from these seed rows averaged 4.39 tons (12-percent moisture) for the 3-year period, with increases due to applied nitrogen in the third year.

A seed-production test with Russian wildrye was conducted for 7 years at Mandan. There was no response to nitrogen fertilizer for the first 3 years, but responses were obtained in the last 4 years. The average production for the 7-year period showed highly significant increases for each added increment of nitrogen up to the highest application of 200 pounds per acre annually. At this rate the average yield was 303 pounds of seed. Average forage yields after seed harvest ranged from 8.6 tons (12-percent moisture) in 1952 to 2.3 tons in 1956. There was no difference in seed or forage yields due to phosphorus application, or time of nitrogen application. Single applications of nitrogen yielded as much as applications that were split.

IRRIGATED CROP ROTATIONS

At Redfield and Upham, crop-rotation studies were made in which rotation, with and without alfalfa, were compared. At Upham, a 3-year cash crop rotation (barley-corn-potatoes) was studied from 1953 to 1957 in comparison with a 6-year legume cash crop rotation (barley-alfalfa-alfalfa-alfalfa-corn-potatoes). In the rotation studies conducted at Redfield from 1949 to 1956 and from 1953 to 1958, 3-year cash crop rotations (barley-corn-corn) were compared with a 5-year legume cash crop rotation (barley-alfalfa-alfalfa-corn-corn).

In all of these studies the objectives were (1) to compare yields of crops growing in a rotation with and without alfalfa, and (2) to evaluate the need for crop response to nitrogen and phosphorus fertilizer in a rotation with and without alfalfa. All crops occurred in the rotation each year. Fertilizer was applied to randomized subplots within each crop block (fig. 22). The data collected from the fertilized subplots provided information on how best to fertilize a rotation.

FIGURE 22.—General view of rotation experiment at Upham, N. Dak.

At Upham, yields of corn following alfalfa were higher for all fertilizer treatments than those in the rotation without alfalfa (table 15). Corn yields at Redfield following alfalfa were higher than the yields in the rotation without alfalfa for treatments not receiving nitrogen fertilizer. However, at Redfield, plots that received nitrogen in the rotation without alfalfa produced yields as high as the same treatment in the rotation with alfalfa. These results suggest that alfalfa contributes considerably to the available soil nitrogen. Similar results have been reported by workers from other locations (*15*, *23*, *36*).

On the plots receiving phosphorus, corn forage yields at Upham, the first year after alfalfa, were 52 percent higher than those in the nonlegume rotation (fig. 23). At Redfield, corn grain yields were 41 percent higher the first year after alfalfa.

Two years after alfalfa, potato yields in the legume rotation at Upham were 39 percent higher

TABLE 15.—*Yields of corn following alfalfa and no alfalfa for various nitrogen and phosphorus treatments at Upham, N. Dak., and Redfield, S. Dak.*[1]

$N-P_2O_5$ applied per acre, pounds	Upham		Redfield	
	No alfalfa	Alfalfa	No alfalfa	Alfalfa
Pounds	*Bushels*	*Bushels*	*Bushels*	*Bushels*
0–0	51. 4	67. 1	56. 2	86. 2
80–0	58. 9	63. 2	101. 0	91. 5
0–50	41. 0	66. 9	61. 5	85. 9
80–50	74. 4	85. 8	101. 0	102. 0

[1] Upham values are averages for 1954–57; Redfield, 1954, 1955, and 1957.

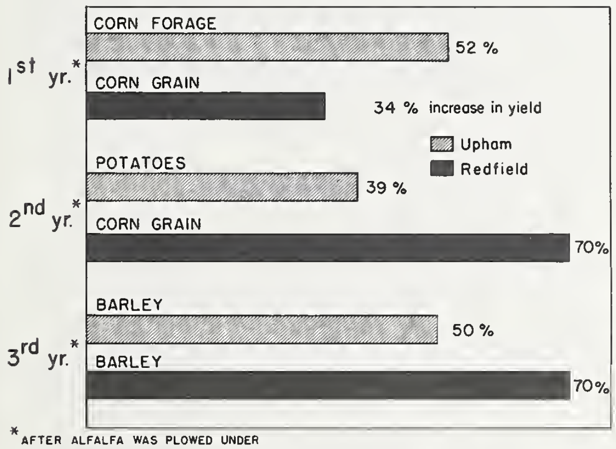

FIGURE 23.—Alfalfa in rotation increases yields of corn forage, corn grain, potatoes, and barley. No nitrogen fertilizer was applied to the treatments shown. (Corn forage yields are on a 12-percent moisture basis.)

and corn grain yields at Redfield were 67 percent higher than in the same treatment of the nonlegume rotation. Barley yields 3 years after alfalfa were 56 percent higher at Upham, and 65 percent higher at Redfield than in the same treatment of the rotation without alfalfa.

These results show that the benefits from alfalfa are considerable for several years after the alfalfa is plowed under. If phosphate is applied to the alfalfa, the need for nitrogen fertilizer for the crops that follow is appreciably reduced.

Barley, planted 3 years after alfalfa at Upham, lodged badly even on the check treatment. The lodging not only reduced the grain yield but also lowered the test weight. Therefore, corn should follow alfalfa rather than a small grain.

In order to get into the sequence of the rotation at the beginning of the Upham and Redfield studies, it was necessary on certain treatments to leave the alfalfa in for only 1 year before plowing it out and planting corn. Yields at both locations show that alfalfa, growing 1 year in the rotation, influenced corn yields as much as alfalfa left in for 3 years. These results suggest that for maximum soil fertility benefits, alfalfa need not be in the rotation for more than 2 years. This time is much shorter than is generally practiced.

The highest cash value crop in a rotation is considered the crop that should receive a liberal application of fertilizer to assure maximum yield, and allow the residue to be used by succeeding crops. At Upham, 120 pounds of nitrogen per acre was applied in three ways to a barley-corn-potato rotation. In one treatment 120 pounds of nitrogen was applied to corn and in another to potatoes; in the third treatment 20, 40, and 60 pounds of nitrogen was applied to barley, corn, and potatoes, respectively.

Potato yields on the plots that received all of the nitrogen were highest, followed by the system that applied nitrogen to all crops in the rotation (table 16). Likewise, corn yields were highest on the treatment that received all of the nitrogen applied to the corn, followed by the system that applied nitrogen to all crops. Barley yields were similar for all nitrogen fertilized treatments.

Responses in the 6-year rotation were similar, but less marked because of the residual nitrogen from the alfalfa. From these data, it appears that in a barley-corn-potato rotation there is an

TABLE 16.—*Crop yields for four methods of fertilizing a barley-corn-potato rotation at Upham, N. Dak.*

N per acre (pounds) applied to—			Crop yields			
Barley	Corn	Potatoes	Potatoes	Corn		Barley
				Forage [1]	Grain	
			Bushels	*Tons*	*Bushels*	*Bushels*
0	0	0	392	3. 97	55. 6	44. 3
0	0	120	550	4. 10	52. 1	56. 4
0	120	0	476	5. 36	76. 8	57. 8
20	40	60	484	4. 55	65. 7	61. 4

[1] 12-percent moisture basis.

advantage to applying all the nitrogen for the 3-year period to the potatoes. The system of applying all the nitrogen to the corn seems to have little advantage over the same rate applied in proportional amounts to all the crops in the rotation.

MANAGEMENT OF SUBSOILS EXPOSED BY LAND LEVELING

Surface soils in the northern Great Plains contain appreciable amounts of the essential elements needed for plant growth and are high in organic matter required for good tilth. Leveling the land for surface irrigation requires removal of topsoil from some portions of the field. Restoring the productivity of exposed subsoils where excessive cuts are made sometimes requires special soil-management practices. Generally, these subsoil areas occupy only a small portion of the field and can be treated separately.

Early work at Mandan and Bowbells showed big differences in yield between "cuts" (surface soil removed), and "undisturbed" or "filled" (surface soil brought in) areas. On the cut areas, available nitrogen was low, and studies with radioactive phosphorus revealed that available soil phosphorus was also very low. A similar problem existed at Upham. Subsoils at Upham were low in nitrogen and phosphorus (table 2). Exchangeable potassium and cation-exchange capacity decreased with depth. Calcium carbonate was low in the top 11 inches but was higher below this level.

On the basis of these analyses, removing the top 6 inches of Gardena loam was equal to removing 3,660 pounds of nitrogen per acre and adding it to some other part of the field. If it can be assumed that soil nitrogen becomes available at the rate of 2 percent per year, a reservoir of 73 pounds per acre of available nitrogen per year has been removed from these areas. A large part of the available phosphorus was also removed in the surface 6 inches of soil.

In 1953 a chlorosis diagnosed as zinc deficiency developed at Upham in corn on an area from which the surface soil had been removed, and yields were very low (fig. 24). Soil analyses indicated that concentrations of zinc in the subsurface horizons were lower than in normal topsoil (table 2). Rainbow flint, an open pollinated variety of corn, was more susceptible to zinc deficiency than was Nodak 301, a hybrid. Spraying the plants with zinc sulfate corrected the deficiency. It also was observed that a strip of corn that had been manured

FIGURE 24.—Corn plants on cut soil (foreground) and on noncut soil (background) at Upham, N. Dak., in 1954.

was not chlorotic. A detailed discussion of zinc deficiency of exposed subsoils is presented elsewhere (*16*).

From these observations and analyses it was concluded that the production problem on exposed subsoil areas was a deficiency of nitrogen, phosphorus, and zinc. Greenhouse and growth chamber results showed that nitrogen was the element most needed, with phosphorus next in importance.

In 1954 two experiments were set up at Upham to evaluate problems involved in restoring the productivity of exposed subsoils (*8*). On one site, 1 foot of surface soil was removed to facilitate gravity irrigation. Key treatments used on the cut area were also used on an adjacent undisturbed area. Nitrogen was applied at the rates of 180, 180, and 120 pounds per acre the first, second, and third year, respectively. The first and third year after leveling, 100 pounds of P_2O_5 was applied, and on the first year 20 tons of manure. A split was made in the original plots the second year to study the residual effects of the fertilizer.

Corn was planted the first and third years after leveling and potatoes the second. Marked early differences in top growth were evident in several fertility treatments in the cut area. Plots receiving high rates of nitrogen with phosphorus had considerable top growth, whereas nitrogen or

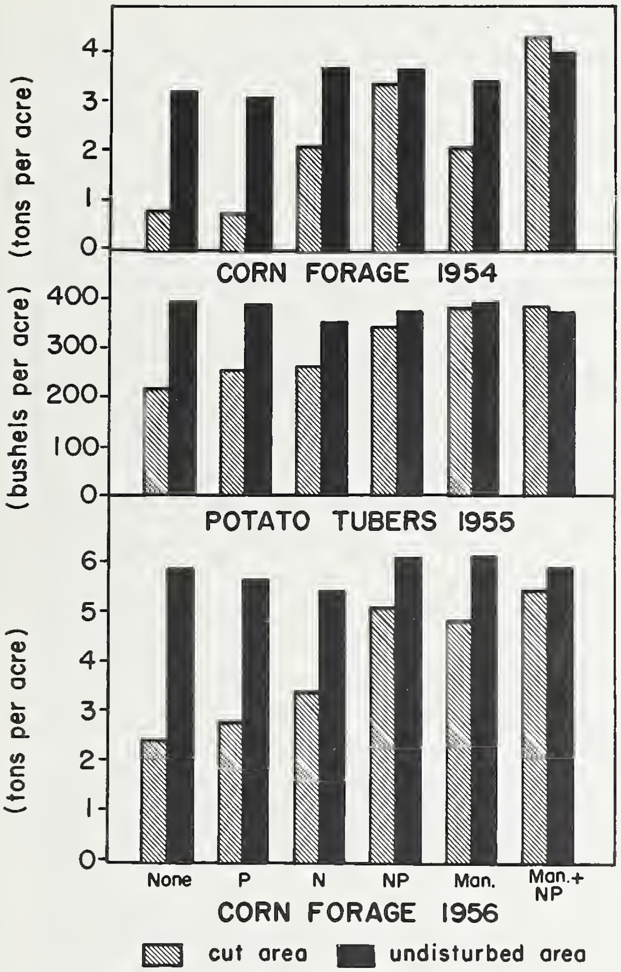

FIGURE 25.—Nitrogen, phosphorus, and manure were required to obtain highest yields on an area with the surface soil removed: *A*, Corn, 1954; *B*, potatoes, 1955; and *C*, corn, 1956. Upham, N. Dak. (Yields of corn forage reported on a 12-percent moisture basis.)

phosphorus alone had little effect on growth. These differences became greater as the season progressed.

Corn forage yields at harvest on the cut area the first year after leveling were similar for the check and phosphorus treatments (fig. 25, *A*). Nitrogen produced yields twice that of the check. Yields were still higher when both nitrogen and phosphorus were added. The treatment that received 180 pounds of nitrogen, 100 pounds of P_2O_5, and 20 tons of manure yielded 4.4 tons of forage per acre compared with 0.8 ton for the treatment receiving no fertilizer (fig. 26).

On the cut area, potato yields the second year after leveling (1955) were similar for the nitrogen

FIGURE 26.—Nitrogen fertilizer increases corn growth on an area with 1 foot of surface soil removed. Plants in the foreground received 100 pounds of P_2O_5 per acre, whereas those in the background received 180 pounds of N and 100 pounds of P_2O_5 at Upham, N. Dak.

and phosphorus treatments, both being slightly higher than the check treatment (fig. 25, *B*). Yields were still higher when both nitrogen and phosphorus were added and were highest following the addition of nitrogen, phosphorus, and manure.

In 1956 corn-forage yields were slightly higher when nitrogen was added than when no fertilizer or only phosphorus was added (fig. 25, *C*). As in previous years, the combined nitrogen and phosphorus applications yielded more than when either material was applied alone. Corn yields in both 1954 and 1956 were less on the manured treatment than on the nitrogen plus phosphorus treatment. However, potato yields were similar for both treatments in 1955.

Where the surface soil had been removed, zinc deficiency symptoms of corn were evident in 1954 on plots receiving neither zinc nor manure. Apparently the zinc present in 20 tons of manure was sufficient to take care of the needs of the corn plant. On plots not receiving manure, 15 pounds of zinc per acre (as zinc sulfate) was required for maximum corn yields. In both 1954 and 1956 grain yields were influenced more by a zinc deficiency than were forage yields. No symptoms of zinc deficiency were evident in potatoes planted the second year after leveling.

Some response to the various fertilizer treatments was evident the first year on the undisturbed area but little or no response occurred the following 2 years (fig. 25). When high rates of nitro-

gen, phosphorus, and manure were applied, yields were similar on the cut and undisturbed areas in all 3 years.

The comparative fertility of one surface and two subsoil horizons at Upham has been studied with barley in the controlled light-temperature plant growth chamber at Mandan (*7*). When phosphorus was added, both the surface and subsoils responded to added nitrogen. Phosphorus markedly increased yields on the subsoils, in the presence of added nitrogen. Some growth response to applied phosphorus was also observed on the surface horizon. Even when minor elements and potassium were added, yields were greater on the surface soil than on the subsoil.

The need for adding phosphorus to a subsoil horizon was reduced by mixing 25 percent of surface soil with the subsoil. It had also been observed in field experiments that mixing some surface soil with the subsoil considerably increased crop yields.

In many soils the physical problems encountered after land leveling seriously reduce crop yields. This problem generally occurs in soils high in clay (*19*) but can be found in fields with small amounts of clay if land is leveled when the soil is wet.

Physical measurements were made on a soil from an Upham field experiment on a cut area and an associated undisturbed area. Results showed that the operations involved in land leveling did not appreciably change the physical properties of that soil. On these cut areas normal yields can be produced after leveling of manure, legumes, and commercial fertilizer are used. Land leveling should not be delayed because of fertility problems encountered. The probability of deficiencies of phosphorus can be predicted reasonably well with soil tests. Deficiencies of nitrogen and minor elements generally can be anticipated. It is recognized that high rates of commercial fertilizer and manure will be needed to get maximum production from these soils.

CONSUMPTIVE USE

Design of both project and farmstead irrigation systems requires knowledge of seasonal and peak consumptive-use rates. Measured consumptive-use data compiled from various locations for the principal irrigated crops grown in the northern Great Plains area are tabulated in table 17.

TABLE 17.—*Measured seasonal consumptive use, net irrigation requirements, and peak daily-use rates for principal crops compiled from various locations in the northern Great Plains*

Crop, location,[1] and year	Measured seasonal consumptive use	Seasonal precipitation	Average net irrigation requirement for period	Long time average seasonal precipitation [2]	Peak use rate per day	Average consumptive use period
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Days*
ALFALFA:						
Upham, 1954–56 [3]	23.4	10.1	13.3	10.8	0.26–.39	143
Redfield, 1950–53 [4]	22.2	13.2	9.0	14.4		124
SUGAR BEETS:						
Huntley, 1953 [5]	22.5	6.5	18.0	8.7	.23	160
Redfield, 1951–53 [4]	24.0	12.1	11.9	14.4		
POTATOES:						
Upham, 1953–56 [3]	18.4	9.2	9.2	10.8	.27–.37	112
Redfield, 1950–53 [4]	15.5	11.5	4.0	14.4		
Mandan, 1953 [6]	17.9	13.4	4.5	10.9	.36	128
CORN:						
Upham, 1953–56 [3]	17.5	8.6	8.9	10.8	.20–.36	107
Redfield, 1951–53 [4]	16.6	10.8	5.8	14.4		
SMALL GRAINS:						
Upham, 1954–56 [3]	15.9	8.0	7.9	10.8	.25–.38	98
Redfield, 1953 [4]	16.3			14.4		
DRY BEANS: Redfield, 1952–53 [4]	16.4			14.4		

[1] Upham and Mandan, N. Dak.; Redfield, S. Dak.; and Huntley, Mont.
[2] Climate and Man. 1941 Yearbook, U.S. Department of Agriculture.
[3] Unpublished data obtained cooperatively between North Dakota Agricultural Experiment Station, Fargo, and Agricultural Research Service, Mandan, N. Dak.
[4] Source: Erie and Dimick (*11*).
[5] Source: Larson and Johnston (*24*).
[6] Unpublished data, H. R. Haise, Agricultural Research Service, formerly at USDA Northern Great Plains Field Station, Mandan, N. Dak.

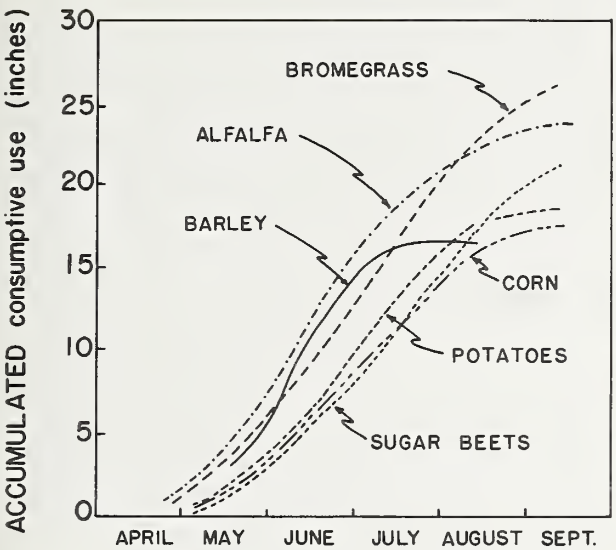

FIGURE 27.—Accumulated consumptive use of various irrigated crops grown in the northern Great Plains.

Seasonal consumptive use includes the amount or depth of water transpired by the crops in addition to that lost by evaporation from the soil surface. Peak-use rate per day represents the highest average daily use of water in inches for a given period of time, usually 7 to 15 days.

Inches of water required to produce a given crop in most instances vary within relatively narrow limits for different locations. In general, alfalfa requires about the same amount of water as sugar beets (approximately 24 inches), potatoes about the same amount as corn (approximately 18 inches), and small grain about the same amount as dry beans (approximately 16 inches). Differences in net radiation, humidity, wind movement, and length of growing season at the various locations account for much of the variability in consumptive-use values obtained. Several publications provide estimates of the consumptive-use requirements of crops in North and South Dakota (*9*, *10*, *11*, *20*). The method of Blaney and Criddle (*4*) was used in obtaining values for most of the crops.

Daily peak-use rates (table 17) were not available for Redfield. At Upham, the range in daily peak-use rates for the 3- or 4-year study are shown. Rates varied in different years as much as 0.16 inch per day for corn, 0.13 inch per day for small grains and alfalfa, and 0.10 inch per day for potatoes. These differences are primarily the result of a relatively wet, cool, growing season compared with a hot dry season. It is noteworthy that the peak use for small grains was as high as that for alfalfa.

FIGURE 28.—Time of irrigation affects corn yields at Redfield, S. Dak. Left—irrigated in tasseling stage only; right—irrigated in milk and denting stage only.

Peak-use rates for most crops occur during the stage of most rapid vegetative growth and generally include the fruiting period. This period of plant development also corresponds to the time when, during June, July, and August, the climate reaches its maximum evaporative potential. Erie and Dimick (*11*) reported peak-use rates for flax about 10 days after blossom; sugar beets, in the middle of the growing season; potatoes, at the time the tubers set; corn, shortly after the silking stage; dry beans, at blossom; and wheat, during the early boot stage.

Accumulative seasonal consumptive-use curves are presented in figure 27, with inset values of monthly use in acre-inches for each crop. Bromegrass and alfalfa show similar water-use characteristics with time. Sugar beets, corn, and potatoes are also closely grouped with the exception of greater late-season use by sugar beets. Peak monthly use for the various crops obtained from inset data occurs in July for bromegrass, in June and July for alfalfa, in August for sugar beets, and in June for potatoes, corn, and barley.

These accumulated curves can be used to determine consumptive use for a given period of time by selecting interval at the bottom of the graph and reading the amount of water used on the left-hand side of the graph. For example, alfalfa used 11.5 inches of water by June 15 and 15.5 inches by July 1, or a total difference of 4.0 inches during

the 2-week period. Such information, when related to available water-holding capacity of soil and crop-rooting depth, is useful in scheduling irrigations of crops indicated.

Yields are seriously reduced when corn plants do not have adequate water during their critical growth period (fig. 28). Moisture deficits for periods of 1 or 2 days during tasseling or pollination resulted in as much as a 22-percent reduction in yields in the State of Washington (*31*).

Potato yields and tuber quality can be seriously decreased by moisture stress at the critical stage (*30*). If the potato plant is subjected to moisture stress at any time during development, the quality of the tubers will be decreased.

SUMMARY OF FERTILIZER RECOMMENDATIONS

Nitrogen

Nitrogen will be the element most needed for all nonlegumes when the soils of North and South Dakota are irrigated (*6*). Rates considerably higher than those presently being used by dryland farmers will be required if high yields are to be obtained. Although ammonium nitrate was generally used in these experiments, ammonium sulfate and sodium nitrate also gave good yield increases. The choice among these nitrogen sources should probably be determined by the cost per pound of nitrogen.

It is recognized that soils within the area will vary in their ability to supply nitrogen to plants. Until the time when satisfactory tests are developed for soil nitrogen, farmers will have to try several rates of nitrogen fertilization to determine which rates will be best for their farm. Results in this publication suggest that in a nonlegume rotation, profitable rates of nitrogen per acre are 80 pounds for corn, 40 pounds for barley, and 100 pounds for potatoes. These rates are lower than those recommended in irrigated regions in Washington (*34*).

Alfalfa leaves considerable residues of available nitrogen in the soil even when the tops are harvested. However, in order to obtain maximum yields, some nitrogen fertilizer is required. For corn planted the year after alfalfa, 40 pounds of nitrogen per acre should be sufficient. Corn or potatoes planted 2 years after alfalfa will require about 50 pounds of nitrogen. Barley grown 3 years after alfalfa should receive 20 pounds of nitrogen.

Grass grown for seed or hay will require per acre rates of nitrogen up to 200 pounds per year. Over 100 pounds of nitrogen will be necessary on pasture seedings unless a legume is included in the mixture.

Experiments with corn, potatoes, and sugar beets indicate no apparent difference in placement method or time of application on yield. Broadcasting before and during seedbed preparation, band placement at seeding time, and application of nitrogen at later stages of growth were all equally effective in increasing yields.

Higher rates of nitrogen fertilizer will be required on cut or eroded areas than on the normal surface soils.

Phosphorus

Soil testing for phosphorus is always advisable, since soils will vary in their requirements for phosphorus fertilization. For the normal soils, phosphorus applied with nitrogen at the rate of 25 pounds of P_2O_5 per acre is satisfactory for corn and small grains, but 50 pounds of P_2O_5 is required for potatoes and alfalfa.

On cut areas 150 pounds of P_2O_5 per acre should be applied the first year after leveling. Subsequent additions of 50 pounds of P_2O_5 annually for corn and small grains and 75 pounds of P_2O_5 annually for potatoes and alfalfa is recommended.

Concentrated superphosphate and ordinary superphosphate have been the phosphorus sources in all the experiments discussed in this manuscript, and have been found to be satisfactory. The recommendations on phosphorus sources in the remaining part of this section are based on work done in other areas.

In accord with the recommendations of Rogers, Pearson, and Ensminger (*32*) mineral phosphates, such as rock phosphate and colloidal phosphate, are not recommended, since the soils in the area are not very acid, and also because the superphosphates are generally a more economical source.

Dicalcium phosphate would not be expected to be as available as superphosphate, except on acid or neutral soils (*32*). Calcium metaphosphate

might be an effective phosphorus source when the fertilizer is mixed with the soil (*33*). However, it would probably be less effective if banded, or surface applied under low moisture.

Nitric phosphate might be an effective phosphorus source, except when surface applied, when moisture was limited (*33*). Ammonium phosphates would probably be good sources of phosphorus on all but acid soils (*32*), and would also be suitable on acid soils if their residual acidity were neutralized with limestone.

Manure

Manure additions will decrease the requirement for added phosphorus. When limited quantities are available, the manure should be placed on cut or eroded areas.

Potassium

Potassium has not given yield increases on either the normal or cut soils.

Zinc

Soil applications of 15 pounds of zinc per acre (as zinc sulfate) have increased yields on cut areas, but have had no effect on noncut areas. The application of 20 tons of manure will also correct zinc deficiency.

Other Fertilizers

No other fertilizers appear to be required on either the normal or cut areas.

SUMMARY OF WATER MANAGEMENT RECOMMENDATIONS

Crops vary considerably in their need for water. During the growing season alfalfa will use about 24 inches of water, whereas corn and potatoes will require about 18 inches. The seasonal requirement for small grains is about 15 to 17 inches.

The amount of water required per day usually is greatest when the plants are growing most rapidly. Peak daily water use for corn occurs about August 1, whereas potatoes and alfalfa use peak amounts early in July. Consumptive-use requirements for small grains are generally greatest late in June.

Most plants have a critical stage of development, at which time the plant must have access to adequate available water or yields will be drastically reduced. The tasseling and silking stage of corn, the boot stage of small grain, and time of potato tuber formation are critical stages.

About 75 percent of the moisture used by plants is taken from the surface 2 feet of soil and about 90 percent from the top 3 feet. This means that the irrigator should attempt to wet the soil to a depth of at least 3 feet for each irrigation. Incomplete wetting of the root zone will result in most plants having a shallow root system.

Excess irrigation generally means that some water is lost by deep percolation. In most cases soluble plant nutrients are also lost and drainage problems are aggravated. In areas where excess soluble salts are a problem, some soil leaching is essential.

PROBLEMS AHEAD

The research discussed in this publication has indicated the potential productivity of lands under irrigation. The areas dealt with are the Garrison Diversion Unit in central and eastern North Dakota, and the Oahe Unit in north-central South Dakota. Some of the problems expected to arise if the area is irrigated are also discussed, but in the main these can be controlled by selection of the areas to be irrigated, adequate fertilization, and good crop and land management and irrigation practices.

Much of the research has been concerned with soil fertility, and with fertilizers required for various crops grown in the different locations. Alfalfa can take the place of some of the nitrogen fertilizer in rotations, but research is needed to determine how long alfalfa should be grown to obtain maximum benefits. Studies should be made to determine how other legumes compare with alfalfa as soil-building crops.

Rotation experiments at Upham have shown that yields of crops following alfalfa are higher than those in rotations without alfalfa, irrespective of fertilizer treatment. Additional studies are needed to determine the causes of these higher yields.

Work is needed on the comparative effectiveness of different phosphorus sources under different

methods of fertilizer placement, and at different soil-moisture levels. The newer sources combining both nitrogen and phosphorus should be of special interest. The effect of long-time fertilization with various nitrogen sources upon soil properties should also be investigated.

Long-time direct comparisons of irrigated versus dryland crop yields should be obtained to evaluate correctly irrigation benefits in newly irrigated areas that already support a profitable dryland economy. Additional determinations on peak and seasonal water-use rates are needed for the principal crops that would be grown under irrigation.

The effect of irrigation on nutrient content of plants should receive additional study. Included should be some research on the effect of irrigation on the availability to crops of soil and fertilizer nitrogen and phosphorus.

Benefits of various cultural and cropping systems need to be evaluated with respect to improvement of intake rates on slowly permeable soils. Studies should be conducted to find ways and means of improving soil structure to facilitate intake, transmission, and storage of water.

It is likely that in some years high intensity rains and generally wet climatic conditions may follow a period of irrigation during which the soils have been fairly well saturated and the underlying water tables are close to the surface. Surface erosion caused by intense rains falling on freshly prepared, irrigated land can also create management problems in this section of the country.

In a large part of the area, a high water table is generally present. If sizable areas are developed and preventive and corrective measures are not taken, drainage undoubtedly will become a problem. Following surveys which delineate areas having significant differences in hydraulic conductivity of soils and substrata and in depths to drainage barriers, studies can be made of drainage design and of costs of drainage facilities required to maintain suitable plant growth environment.

Results suggest that a livestock program offers the best opportunity for a successful operation under irrigation in this area. Investigations are needed on irrigated pasture management. The problem of bloat in cattle and sheep has discouraged many operators from considering pastures. Climate in the area has made the harvest and curing of hay a serious problem, and information is needed on how these crops can be best handled.

Winter injury to legumes and grasses has damaged a large percentage of the stands during some winters. Investigations should be made to determine what factors are involved, and how winter injury can be decreased.

Studies designed to devise management procedures which will decrease soil crusting and facilitate establishment of small seeded grasses and legumes are needed. Means should be found for maintaining favorable surface and subsurface soil conditions.

Experiments are needed on both the physical and chemical problems associated with land forming necessary for surface irrigation methods. One problem requiring additional study is plant nutrition on subsoils that have been exposed during land leveling and are low in organic matter and high in lime.

The research discussed in this publication has dealt primarily with effects measured over comparatively few years. Some work should be conducted for longer periods of time to assure that high yields and sustained soil fertility can be maintained.

Finally, more basic chemical and physical data are needed on the soils in the area. Such information would assist in identifying those conditions that require special attention if the area were to be placed under irrigation. It would also assist in determining the fertilizers needed and water requirements to obtain good crop yields.

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